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AIR POLLUTION ASPECTS OF IRON AND ITS COMPOUNDS

Ralph J. Sullivan

Litton Systems, Incorporated
Bethesda, Maryland

September 1969

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AIR POLLUTION ASPECTS

OF

IRON AND ITS COMPOUNDS

Prepared for the
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Compiled by Ralph J. Sullivan

Litton Systems, Inc.
Environmental Systems Division
7300 Pearl Street
Bethesda, Maryland 20014

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FOREWORD

As the concern for air quality grows, so does the concern over the less ubiquitous but potentially harmful contaminants that are in our atmosphere. Thirty such pollutants have been identified, and available information has been summarized in a series of reports describing their sources, distribution, effects, and control technology for their abatement.

A total of 27 reports have been prepared covering the 30 pollutants. These reports were developed under contract for the National Air Pollution Control Administration (NAPCA) by Litton Systems, Inc. The complete listing is as follows:

Aeroallergens (pollens)
Aldehydes (includes acrolein and formaldehyde)
Ammonia
Arsenic and Its Compounds
Asbestos
Barium and Its Compounds
Beryllium and Its Compounds
Biological Aerosols (microorganisms)
Boron and Its Compounds
Cadmium and Its Compounds
Chlorine Gas
Chromium and Its Compounds (includes chromic acid)
Ethylene
Hydrochloric Acid
Hydrogen Sulfide
Iron and Its Compounds
Manganese and Its Compounds
Mercury and Its Compounds
Nickel and Its Compounds
Odorous Compounds
Organic Carcinogens
Pesticides
Phosphorus and Its Compounds
Radioactive Substances
Selenium and Its Compounds
Vanadium and Its Compounds
Zinc and Its Compounds

These reports represent current state-of-the-art literature reviews supplemented by discussions with selected knowledgeable individuals both within and outside the Federal Government. They do not however presume to be a synthesis of available information but rather a summary without an attempt to interpret or reconcile conflicting data. The reports are necessarily limited in their discussion of health effects for some pollutants to descriptions of occupational health exposures and animal laboratory studies since only a few epidemiologic studies were available.

Initially these reports were generally intended as internal documents within NAPCA to provide a basis for sound decision-making on program guidance for future research activities and to allow ranking of future activities relating to the development of criteria and control technology documents. However, it is apparent that these reports may also be of significant value to many others in air pollution control, such as State or local air pollution control officials, as a library of information on which to base informed decisions on pollutants to be controlled in their geographic areas. Additionally, these reports may stimulate scientific investigators to pursue research in needed areas. They also provide for the interested citizen readily available information about a given pollutant. Therefore, they are being given wide distribution with the assumption that they will be used with full knowledge of their value and limitations.

This series of reports was compiled and prepared by the Litton personnel listed below:

Ralph J. Sullivan
Quade R. Stahl, Ph.D.
Norman L. Durocher
Yanis C. Athanassiadis
Sydney Miner
Harold Finkelstein, Ph.D.
Douglas A. Olsen, Ph.D.
James L. Haynes

The NAPCA project officer for the contract was Ronald C. Campbell, assisted by Dr. Emanuel Landau and Gerald Chapman.

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ABSTRACT

Iron and its compounds present as pollutants in the atmosphere can cause deleterious effects to humans, animals, and materials. Iron and iron oxide are known to produce a benign siderosis, and iron oxides have been implicated as a vehicle for transporting high concentrations of both carcinogens and sulfur dioxide deep into the lungs thereby enhancing the activity of these pollutants. Iron oxide also causes damage by staining materials.

Analyses of urban air samples show that the iron content averages 1.6 $\mu g/m^3$, with the iron and steel industry probably the most likely source of emission. Pollution by iron emission can be reduced by use of particulate control equipment. No information has been found on the economic costs of iron air pollution; costs of pollution abatement for basic oxygen furnaces run between 14 to 19 percent of total industrial plant costs. Adequate methods exist for the determination of iron in the ambient air.

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: Iron and iron compounds

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1. INTRODUCTION

Although inhalation of iron or iron oxide is believed to cause a benign pneumoconiosis,[128] there is growing concern about its synergistic effects with sulfur dioxide and carcinogens.[129] Iron may also reduce visibility[32] and cause material damage by staining paint.[49]

2. EFFECTS

Because of the sparsity of known effects of iron air pollution at the concentrations found in the ambient air, industrial and experimental observations have been reviewed to indicate the effects which might be expected from iron pollution.

2.1 Effects on Humans

Inhalation of iron or iron oxide fumes or dust by workers in the iron and steel industry has caused siderosis, an iron pigmentation of the lungs,[128] a benign condition recognizable by X-ray.[51] Pendergrass and Leopold[96] described the condition as a benign pneumoconiosis. More recent literature has indicated a possible symptomatic pneumoconiosis. Kleinfeld *et al*.[69] cited the work of Sadoul *et al*.[109] in Lorraine, France, where 575 iron-ore miners after long exposure* (50 percent for over 25 years) frequently developed chronic bronchitis and emphysema. However, the correlation between these symptoms and the X-ray findings of pneumoconiosis was low.

Kleinfeld *et al*.[69] in a comparison of 41 magnetite miners, 16 sinterers (exposed predominantly to iron oxide dust), and 18 healthy unexposed men found pneumoconiosis in one sinterer and six miners. Respiratory symptoms of cough and dyspnea were present, but the sinterers showed no significant difference from the control group. Although the average exposure in both groups was greater than 27 years, there was no consistent correlation between the clinical, radiologic, and pulmonary-function findings and duration of exposure.

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*The reader should bear in mind that in this study and most of the others, iron oxide, although comprising a high percentage of the concentration, is not the only dust present. It is accompanied by small amounts of metals, silicates, and free silica.

Roshchin[107] investigated the health of 41 workers in a Bessemer shop. These workers were exposed to dust containing 85 to 93 percent iron oxides, associated with silica and oxides of chromium, manganese, and vanadium. The dust concentration ranged between 10,000 and 100,000 $\mu g/m^3$, with the average about 30,000-50,000 $\mu g/m^3$. He found seven cases of pneumoconiosis and three cases of suspected pneumoconiosis. All of these workers had been exposed for 12 to 18 years. He concluded that exposure to iron dust produces a variety of pneumoconiosis that develops and progresses at a relatively slow rate.

Exposure to mixed industrial dusts containing mostly iron oxide produces siderosis,[75] metal-fume fever,[8,77] silicosis,[39,14] pneumoconiosis, etc. It appears that iron alone will not cause fibrosis, but small amounts of other pollutants--such as zinc, silicon, sulfur dioxide, carcinogens, etc.--may produce this condition.

The clearance of iron ore--especially hematite (Fe_2O_3)--from the lung has been studied[39,14] by use of radioactive iron-59.[20] Bronchial clearance occurs in two distinct phases. The first phase is completed in 2 to 4 hours, and the second phase requires about 10 to 18 hours. These clearances are also a function of particle size: iron oxide particles 3 μ* in diameter (which deposit largely in the deeper part of the lung and a relatively small amount in the bronchial tree) are cleared almost entirely in the 10- to 18-hour phase.[77] The iron oxide is phagocytized by the so-called "dust cells" and eliminated via the bronchi and lymphatic channels. Lung saturation with iron oxide dust causes an accumulation at the peribronchial and perivascular lymphatic spaces, in the lymphatic channels under the pleura, and at the lymph nodes.[73]

2.1.1 Carcinogenesis

A carcinogenic role of iron oxide has been suggested. Faulds[46] reported progressive, massive fibrosis among Cumberland iron-ore miners. This was accompanied by a high incidence of lung tumors: out of 238 necropsies there were 24 cases of carcinoma, compared to one-third of this number in non-miners. However, the exact role of iron oxide is difficult to assess in exposure to a complex environment where silica and other dusts are sure to be present. Bonser _et al_.[21] suggest that iron oxide may be synergistic in converting the fibrosis caused by silica into a carcinogenic process.

Stokinger and Coffin[129] have discussed the importance of the enhancement of carcinogenic action of organic carcinogens, such as benzo(a)pyrene, by seemingly inert particles. Iron oxide in particular appears to have properties which contribute to cancer production. These authors cite the work of Saffiotti et al.,[110,111,112] who have produced a variety of malignant tumors in the lungs of hamsters. Iron oxide was used as an inert carrier to transport adsorbed benzo(a)pyrene deep into the lung. The animals were intratracheally injected with a saline suspension of benzo(a)pyrene adsorbed on hematite (Fe_2O_3)[a] in amounts equivalent to 3,000 μg of each chemical. Fifteen weekly injections were given. Two important facts were revealed in this study: (1) a high incidence[b] of lung cancer was produced—in as many as 100 percent of the animals in some experiments; and (2) these lung cancers mimicked all the cell types seen in human lung cancers, such as squamous cell carcinoma, anaplastic carcinoma, adenocarcinoma, and even tracheal cancers. Dose response effects were indicated, as were possibilities that a single high dose could induce cancers in the system. According to Saffiotti et al.,[111] the increased carcinogenic action of benzo(a)pyrene is due to the iron oxide, which penetrates the bronchial and alveolar walls and enters into the lung tissues without extensive damage or destruction of the ciliary and mucous barrier; the iron oxide thus acts as a vehicle to transport the carcinogen to the lung tissues. The carcinogen is then eluted from the particulates and diffuses through the tissue. Saffiotti et al.[111] surmise that the rate of removal of benzo(a)pyrene from the respiratory tract is slowed by action of the inert dust as it is stored in macrophages. Thus the carcinogen remains in the lung unmetabolized in high local concentrations, an important factor in producing cancer with benzo(a)pyrene.[129] Saffiotti et al.[111] suggest that this mechanism is a realistic approach to what actually occurs in nature as man breathes the polluted air: that is carcinogens adsorb on ferric oxide or other "inert" particles that act as vehicles to transport the carcinogens into the lungs through the respiratory tract lining to the lung tissues, where the carcinogens are eluted by the cell plasma.

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*μ: micron(s).

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[a] Iron oxide was chosen as the carrier dust because it does not have any extremely irritating or toxic effects. Saffiotti believes that in order to carry the carcinogen in high concentrations to healthy cells, an inert carrier is required—that is, a carrier which does not destroy the cells.

[b] Benzo(a)pyrene alone has induced cancer in the lungs of experimental animals, but usually with some difficulty and in low yield.

Haddow and Horning[54] suggest a possible role of iron in cancer produced with the complex of iron-dextran. However, Neukomm[91] has tested organic iron complexes for carcinogenic power on mice. He was unable to induce cancer with iron complexes of polysomaltosate, plymaltosate, or iron-dextran. However, he did induce sarcoma in 6 percent of the mice with a ferric hydroxide ($Fe(OH)_3$) complex of nitrilo-tri-propionic acid that decomposed at the point of injection and did not reabsorb for more than one year.

2.1.2 Synergism

The synergistic effects of iron compounds with certain gases may be important when considering iron as an air pollutant. Stokinger and Coffin[129] have discussed the possible enhancement of effects when particulate material adsorbs a substance such as sulfur dioxide and carries it deep into the lung in a high local concentration.

Amdur and Underhill[10] studied the effect of various aerosols on the response of guinea pigs to sulfur dioxide. Iron oxide fumes or open-hearth dust alone produced no alteration in pulmonary flow resistance, nor were there any synergistic effects with sulfur dioxide. However, soluble iron such as ferrous sulfate did prove to be synergistic with sulfur dioxide. The ferrous ion probably catalyzes the oxidation of sulfur dioxide to sulfur trioxide, which forms sulfuric acid. (See Section 2.4.)

Smith _et al._[119] in a joint effort by the National Air Pollution Control Administration and Oak Ridge National Laboratory studied the adsorption of sulfur dioxide (labeled with radioactive sulfur-35) on iron oxide (Fe_3O_4) and aluminum oxide (Al_2O_3) aerosols at ambient conditions. Preferential chemisorption was observed at low sulfur dioxide concentrations, and physical adsorption of multilayers was observed at higher concentrations. The data show that monolayer coverage on iron oxide is achieved at 2 ppm sulfur dioxide; and at 66 ppm, 75 monolayers of sulfur dioxide are adsorbed on the iron oxide.

The carcinogenic effects described above are also synergistic.

2.1.3 Nutrition

The nutritional requirements for iron are small and vary somewhat with sex and age.[55] The human adult absorbs less than 5 mg of iron per day. Excess iron is stored in the liver and spleen in the form of ferritin, a trace element that is a vital constituent of every mammalian cell. Iron is closely associated with hemoglobin in transporting oxygen from the lung to tissue cells and plays a role in the oxidation mechanism in body processes. Iron is frequently spoken of as a "one-way" substance. Once it is absorbed by the body, usually in the ferrous state, there is no efficient way of excreting it. Ferrous iron as the sulfate or gluconate is frequently administered to treat iron-deficiency anemia. Most acute cases of iron poisoning result from children's taking ferrous sulfate tablets.[142]

2.1.4 Iron Pentacarbonyl

Iron pentacarbonyl, a yellow-brown flammable liquid,[23] boils at 102.5°C and has a vapor pressure of 40 mm mercury at 30.3°C. It may be present where high partial pressures of carbon monoxide come into contact with iron and steel. This substance has also been used as an antiknock agent. Brief *et al.*[23] have summarized the toxicity studies and recommended that the concentration for industrial workers be maintained at less than 0.1 ppm (800 $\mu g/m^3$).

2.2 Effects on Animals

2.2.1 Commercial and Domestic Animals

No evidence of lung damage was found in three horses which had been exposed to iron oxide dust during a lifetime of work in a coal mine.[43]

2.2.2 Experimental Animals

The data obtained from experimental animals has been discussed in Section 2.1.

2.3 Effects on Plants

No information has been found on plant damage by iron air pollution. However, iron is an essential element in plant nutrition.

2.4 Effects on Materials

Iron or iron oxide air pollution may cause soiling of textiles or staining of buildings and paints. It may also reduce visibility or combine chemically with other materials.

Damage to automobile paint was observed by Fochtman and Langer[49] in a Chicago parking lot. Iron particles from a steel spring grinding operation were airborne to the nearby parking lot where they were deposited and produced brown stains. Many of the cars had to be repainted. The exact mechanism for the paint damage was not determined. However, the authors postulate that the iron is oxidized either in the air or after it is deposited, and forms ferrous hydroxide

The National Air Pollution Control Administration has issued a document, Air Quality Criteria for Particulate Matter. This document gives criteria data which can be used as guidelines in developing ambient air quality standards for total particulate matter.

Although no State criteria for ambient air concentrations of iron were found, some States have laws to control the particulate emissions from the iron and steel industry.[33,34] The Illinois law appears to be most specific:

> "3-3.2112 All new blast furnaces shall be equipped with gas cleaning devices and so operated as to reduce the particulate matter in gases discharged to the atmosphere after burning to contain no more than 0.05 grains of particulate matter per standard cubic foot (0.11 g/m^3).
>
> "3-3.2113 Excess blast furnace gases being bled to the atmosphere shall contain no more than 0.10 grains of particulate matter per standard cubic foot (0.23 g/m^3) and gases shall be burned as bled to the atmosphere.
>
> "3-3.2114 The provisions of Rule 3-3.2112 shall

upon absorbing water from rain or dew. This ferrous hydroxide, in the form of a colloid, penetrates the paint surface, loses water, and oxidizes to become a stable iron oxide. Upon examination, material from the stain was found to be magnetic and to contain small particles of iron. The air concentrations of iron which caused the damage ranged between 11 and 63 μg/m³.

Small quantities of soluble iron and other metals have been observed in rainwater. These water-soluble particulates are potential sources of osmatic blistering. In one laboratory study, the presence of 0.1 ppm iron in water in an accelerated weathering apparatus produced yellow staining.

Iron catalyzes the oxidation of sulfur dioxide to sulfur trioxide, which in the presence of water will form sulfuric acid. The ferric oxide also reacts with the sulfur trioxide to produce ferric sulfate. At room temperature, the reaction proceeds almost to completion before equilibrium is reached.

$$2SO_2 + O_2 \xrightarrow{Fe_2O_3 \text{ or } Fe^{+3}} 2SO_3$$

$$Fe_2O_3 + 3SO_3 \xrightarrow{Fe_2O_3 \text{ or } Fe+3} Fe_2(SO_4)_3$$

Bracewell and Gall[22] have studied the rate of oxidation of sulfur dioxide to sulfur trioxide catalyzed by ferric ion. Assuming a typical fog with a water concentration of 200,000 μg/m³, a ferric ion concentration of 3 μg/m³, and a sulfur dioxide concentration of 1,750 μg/m³ (0.5 ppm), the rate of oxidation would be about 7.7 μg/m^3 per hour. Smith et al.[120] studied the adsorption of gases on aerosols. Of 17 metals tested, iron ranked 14th in decreasing adsorption capacity.

Certain physical properties of iron oxide fumes are characteristic of emissions from steel melting processes.[114,24] Specifically, these particles have a strong tendency to adhere to both natural and synthetic fabric surfaces and a high refractive index, which enhances the reduction of visibility.[32,105] They are also difficult to wet and possess a high electrical resistivity. Furthermore, the particle-size distributions show that the particles are predominantly (approximately 70 percent by weight) less than 5 μ in diameter. Electron photomicrographs indicate that about 95 percent of the particles are less than 0.5 μ in diameter. Thus, the small particle size and high refractive index may cause such light scattering that the reduction in visibility may be the limiting effect when criteria are established.[32] The larger particles are undoubtedly due to the high agglomeration tendency of these particles.

2.5 Environmental Air Standards

The American Industrial Hygiene Association has set air quality criteria for iron oxides.[32] These criteria are "based on the annoyance effects of visibility reduction and soiling inasmuch as no health effects can be demonstrated... the iron oxide concentration should not exceed 50 percent of the air quality criteria for total suspended particulate."

TABLE 1

AIR QUALITY CRITERIA FOR IRON OXIDE RECOMMENDED BY AIHA IN 1968

Location	24-Hour Maximum ($\mu g/m^3$)	30-Day Maximum ($\mu g/m^3$)
Rural	100	
Residential	150	
Commercial	200	
Industrial	250	100

The American Conference of Governmental Industrial Hygienists reduced their recommended value from 15,000 $\mu g/m^3$ to 10,000 $\mu g/m^3$ in 1967. This, of course, is an 8-hour limit for industrial workers.[136]

Brief et al.[23] suggested the following iron pentacarbonyl exposure limits for industrial workers.

TABLE 2

SUGGESTED EXPOSURE LIMIT TO IRON PENTACARBONYL

Criterion	Concentration of $Fe(CO)_5$	
	ppm	$\mu g/m^3$
Target value	0.1	800
Require respiratory protection	0.5-5	4,000-40,000
Shut-down operation	> 5	> 40,000

The National Air Pollution Control Administration has issued a document, Air Quality Criteria for Particulate Matter, which concludes that adverse effects may occur when the total particulate exceeds 60 $\mu g/m^3$, adverse health effects may occur when the total particulate exceeds 80 $\mu g/m^3$, and visibility reduction may occur when the total particulate exceeds 150 $\mu g/m^3$.[4]

Although no State criteria for ambient air concentrations of iron were found, some States have laws to control the particulate emissions from the iron and steel industry.[33,34] The Illinois law appears to be most specific:

> "3-3.2112 All new blast furnaces shall be equipped with gas cleaning devices and so operated as to reduce the particulate matter in gases discharged to the atmosphere after burning to contain no more than 0.05 grains of particulate matter per standard cubic foot (0.11 g/m^3).
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> "3-3.2113 Excess blast furnace gases being bled to the atmosphere shall contain no more than 0.10 grains of particulate matter per standard cubic foot (0.23 g/m^3) and gases shall be burned as bled to the atmosphere.
>
> "3-3.2114 The provisions of Rule 3-3.2112 shall

not apply during irregular movements of the furnace burden when it is necessary to open relief valves at the top of the furnace for safe operation. . . .

"3-3.2132 All new sintering plants, open-hearth furnaces, electric furnaces, and basic oxygen furnaces shall be equipped with gas cleaning devices as necessary to reduce the particulate matter in the gas discharged to the atmosphere so that it does not exceed 0.10 grains per standard cubic foot (0.23 g/m³) of exhaust gas.

"3-3.2133 The provisions of Rule 3-3.2132 shall not apply to electric furnaces and basic oxygen furnaces when the gas collection system must be disconnected from the furnace as in charging and pouring."

After investigating the health of workers in a Bessemer shop in the USSR, Roshchin[107] recommended that dust concentration (approximately 90 percent iron oxides) should not exceed 6,000 μg/m³.

3. SOURCES

3.1 Natural Occurrence

Iron abounds in nature and is an essential element for both animals and plants. The iron content of the earth's crust has been calculated at 5.6 percent.[83] A fractional part of this has been concentrated, under varying geologic conditions, in widely distributed deposits formed in many rock types. Of the various commercial deposits, the most productive to date have been the following: (1) sedimentary hematitic deposits of primary ore enriched by weathering processes, (2) hematite and magnetite deposits of complex origin in metamorphic rocks, and (3) replacement and vein deposits. The locations of deposits in the U.S. are shown in Table 3 in the Appendix.

Open-pit mines produce approximately 90 percent of the iron ore in the United States. The trend has been toward more open-pit mining and less underground mining.

3.2 Production Sources

3.2.1 Iron and Steel Industry

Measurements of particulate concentrations in the area downwind of iron and steel plants have shown that these emissions can contribute significantly to air pollution. In a report[64] of a study in Ironton, Ohio, during the period September 1965 to August 1967, particulates measured downwind from two iron and steel plants ranged between 190 and

212 μg/m³. The iron content of one sample was 16 percent by weight. Estimates of the dust concentrations from open-hearth furnaces indicated that the concentration might exceed 1,000 μg/m³ at a distance of 4 km from the source, if the wind conditions were right. Dust emission rates from the Dayton Malleable Iron Plant were 935 tons per year and from the Armco Steel Corporation, 7,926 tons per year.

Schueneman, High, and Bye,[114] in an excellent review of the air pollution aspects of the iron and steel industry, have reported a significant difference in the air pollutants when steel mills are shut down during strikes. In their report, four steel-producing areas were studied during the 1956 steel strike.

Comparison of analytical results during and after the strike showed that (1) suspended particulate concentrations were higher by 44 to 171 percent in the post-strike period, (2) the soiling index was higher by 200 percent, and (3) the concentration of iron was higher by 2.6 to 10.8 times.

In the upper Ohio River Valley where two major steel mills, two large coke plants, and a steam-powered electric-generating plant were located, the suspended particulate concentration was 383 μg/m³ and 186 μg/m³ in two nearby cities. A maximum of 1,238 μg/m³ was measured in one city. One particulate sample from that city had an iron concentration of

30.8 µg/m^3. The soiling index averaged 5.5 to 5.3 cohs* per 1,000 linear feet.

In a Pennsylvania town where the industry consisted of steel mills with two blast furnaces, 11 open-hearth furnaces, a sintering plant and other equipment, and a zinc plant, the particulate concentration near the furnaces frequently exceeded 500 µg/m^3 at a distance of 0.25 to 0.5 mile from the furnaces after the strike.

In a Michigan community, the iron concentration measured near two coke plants was 5.8 µg/m^3 compared to a value of 0.6 µg/m^3 in a residential area.

In another small community (500 population) the processing of blast furnace slag was found to be a major source of pollution. Particulate concentrations downwind from the slag processing plant 0.4 and 0.8 miles measured an average of 411,000 µg/m^3 and 477,000 µg/m^3 respectively. While other pollution sources could have contributed to the particulate air pollution, chemical analyses indicated that from 35 to nearly 100 percent of the dust came from the slag processing plant.

These community studies indicate that the iron and steel industry may be a significant source of iron air pollution. The distribution of the steel industry is shown in Figure 1 and listed in Table 4 in the Appendix. Although

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*Coh:coefficient of haze

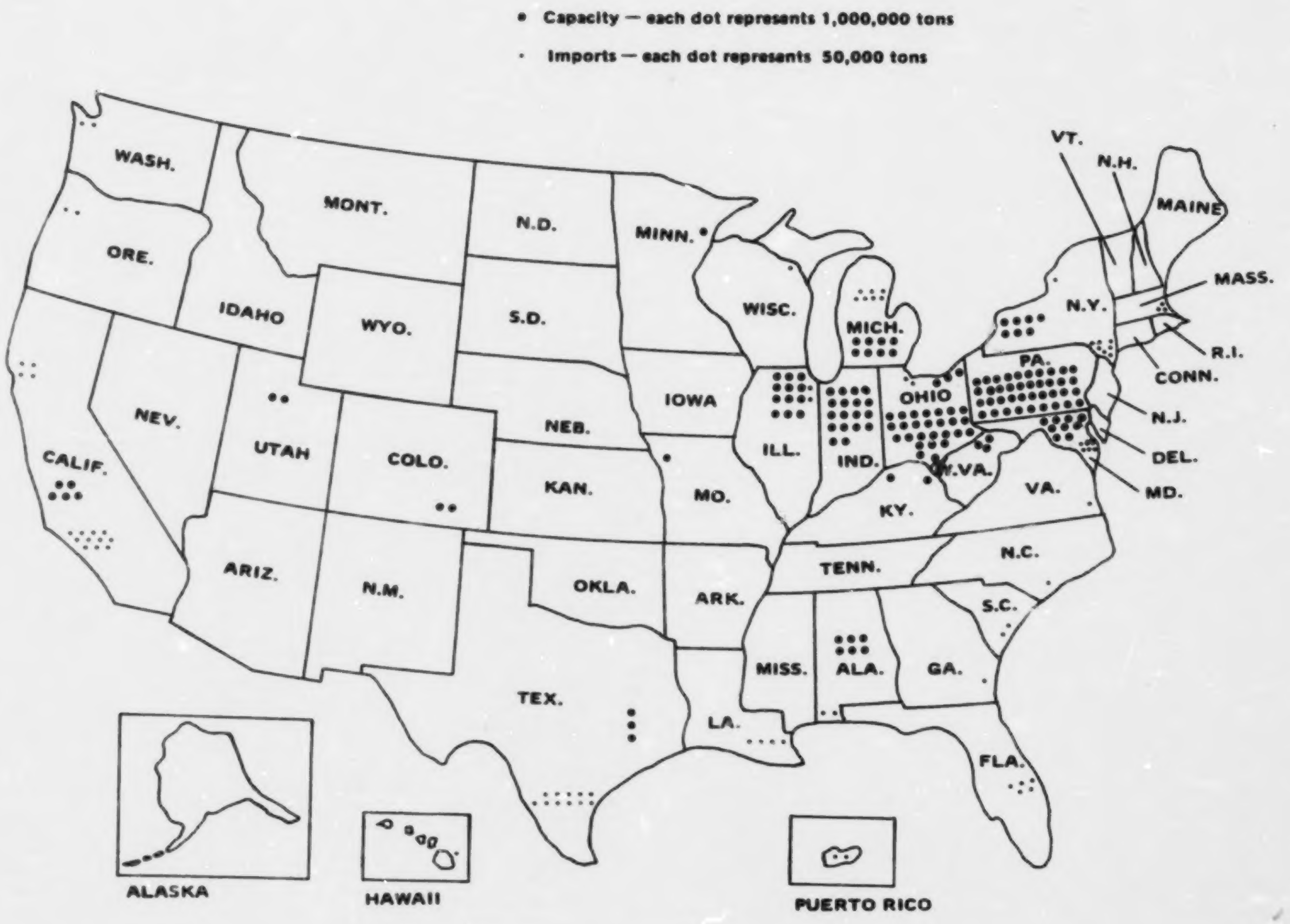
• Capacity — each dot represents 1,000,000 tons
· Imports — each dot represents 50,000 tons
WASH.
ORE.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
COLO.
ARIZ.
N.M.
N.D.
S.D.
NEB.
KAN.
OKLA.
TEX.
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MICH.
IND.
OHIO
KY.
TENN.
MISS.
ALA.
GA.
FLA.
S.C.
N.C.
VA.
W.VA.
PA.
N.Y.
VT.
N.H.
MAINE
MASS.
R.I.
CONN.
N.J.
DEL.
MD.
ALASKA
HAWAII
PUERTO RICO

FIGURE 1

Location of Basic Steel Industry Capacity by State and Steel Product Imports by Port of Entry the production of iron and steel in the United States is increasing, as shown in Table 5 and 6 in the Appendix, the air pollution trend by steel production is uncertain. The main reason for the uncertain pollution trend is the remarkable change in steel processing. The Bessemer process has almost entirely been discontinued while the relatively new basic oxygen process has become increasingly important.[11] This has an impact on the air pollution aspects of the iron and steel industry since old furnaces without dust control are being replaced with new furnaces with such control. While every basic oxygen furnace constructed in the U.S. has been equipped with dust control devices,[114] Vincent and McGinnity[140] have indicated that there are several factors which have tended to increase air pollution from oxygen processes:

1) Fume generation rates in basic oxygen furnaces are approximately six times those of open-hearth furnaces without oxygen lancing.

2) The oxygen-blowing rates of many basic oxygen furnaces have been increased considerably beyond the original design rate. As a result, the control systems have become overloaded, resulting in the emission of copious amounts of fumes.

3) Oxygen lancing has been used to increase the production rate (See Section 3.2.1.4) in open-hearth

furnaces. Because many of the open-hearth furnaces lack dust control, oxygen lancing has resulted in increased emissions from these sources.

Typical emissions from various types of metallurgical furnaces are given in Table 7 in the Appendix.

3.2.1.1 Sintering Plants

From U.S. sintering plants, 20 pounds of dust per ton of sinter is likely in a waste gas of 160 scfm.[a] This gas ranges in temperature from 160° to 390°F, and contains 1.1 to 6.8 g/m³ (0.5 to 3 grains/scf[b]). Dust from a plant in Germany is reported to contain 50 percent iron.[42]

3.2.1.2 Blast Furnaces

The average blast furnace produces approximately 1,000 tons of pig iron per day, during which about 100 tons of dust are produced. The input to the furnace is approximately 2,000 tons of ore, 900 tons of coke, 400 tons of limestone and dolomite, and 3,570 tons of air. The normal emissions are 16,000,000 to 22,800,000 μg/m³. Approximately 32 percent of the dust is fine particulates containing 30 percent iron.[114]

"Slips" are the principal factors in pollution arising from modern blast furnaces having typical air pollution control equipment. A slip occurs when the crust of a furnace charge breaks and slips into a void. This produces a sudden rush of gas which automatically bypasses the control equipment (to avoid high pressures in the system), thus releasing a large black or red cloud of dust to the atmosphere. In recent years automation has helped to reduce the number of slips.[114]

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[a] scfm - standard cubic feet per minute.

[b] scf - standard cubic feet.

3.2.1.3 Ferromanganese Blast Furnaces

Uncontrolled emissions from a ferromanganese blast furnace in 1951 produced as much as 8.2 to 15.5 g/m^3 of exhaust gas, with an average of 13.7 g/m^3. Two 350-ton furnaces produced approximately 142 tons of dust per day containing 0.3 to 0.5 percent iron. The particle size of the fume is extremely small, 0.1 to 1.0 μ in diameter.[114]

3.2.1.4 Open-Hearth Furnaces

For economic reasons, oxygen injection is used to increase the yield of steel from open-hearth furnaces. However, it also increases the air pollution.[114] In 1960, the fume loading was reported to increase from approximately 0.9 g/m^3 (7.5 lb/ton) to 1.4 g/m^3 (9.3 lb/ton) using oxygen injection. This represents about a 50 percent increase in emissions per unit time, but only about a 25 percent increase in emissions per ton.[114] More recent evidence, according to Vincent and McGinnity,[140] indicates the emission rates range from 15 to 40 lb/ton of steel. When the heat time is short (3 hours) the emission rates would be 30 to 40 lb/ton.

The average open-hearth furnace in the U.S. has a capacity of about 175 tons of steel per heat. A heat takes about 11 hours without oxygen injection, but only 3 hours (in short heats) with oxygen injection.

Most of the dust is made up of iron oxide, predominantly Fe_2O_3. If the heat contains a large fraction of galvanized steel, zinc oxides may predominate. Studies[114] have shown that the iron oxide content averages about 50 percent of the total particulates with oxygen lancing. These particles are small, 93 percent of them less than 40 μ in diameter and 46 percent less than 5 μ.

3.2.1.5 Electric-Arc Furnaces

Dust and fume emissions from an electric-arc furnace average 10.5 lb/ton of steel melted, ranging from 4.5 to 29.4 lb/ton. These particulates contain 40 to 50 percent Fe_2O_3 with 70 percent of the particles less than 5 μ in diameter.

3.2.1.6 Basic Oxygen Furnaces

The basic oxygen furnace appears to be the most important furnace for the future. (See Sections 3.2.1 and 4.1) Fortunately, all of the basic oxygen furnaces operating in this country in 1960 were equipped with either wet scrubbers or electrostatic precipitators.[114] Emissions from these control devices range between 55,000 $\mu g/m^3$ and 220,000 $\mu g/m^3$; emission rates of 0.5 to 1 ton/hr have been reduced to about 10 to 20 lb/hr. However, uncontrolled emissions range from 20 to 60 lb/ton of steel with an average of 40 lb/ton.[156]

3.2.1.7 Gray Iron Cupola

The gray iron cupola[127] is still used to melt over 93 percent of the gray iron produced in the U.S. There are over 6,000 foundries which use over 3,300 cupolas. These cupolas range in capacity from 1 to over 50 tons/hr. While the quantity and concentration of iron in the dust and fume emitted is dependent on the quality of scrap melted, tests indicate that emissions range from 10-45 pounds of dust per ton of melt. From 15 to 55 percent of the particles from these emissions measure less than 50 μ, and 6 to 25 percent less than 10 μ.

3.2.2 Coal

In general, the fly ash in coal contains 2 to 26.8 percent iron as Fe_2O_3 or Fe_3O_4, while the average concentration in West Virginia coal ash is 15.9 percent. The fly ash may range from 1 to 10 percent of the coal burned.[123] Cuffe and Gerstle[36] have reported emissions of iron ranging from 2 to 37 lb/ton (0.1 to 1.8 percent) before fly-ash collection and 0.09 to 4 lb/ton (0.004 to 0.2 percent) after collection, depending on the type of equipment. These data are given in Table 8 in the Appendix. Pursglove[101] has estimated that 6,000,000 tons/year of coal fly ash will be produced in the Ohio River Valley by 1971. This fly ash would yield 1,200,000 tons of iron oxide which could make 1,000,000 tons/year of good, high-grade iron pellets for use in blast furnaces.

Iron usually occurs in coal as pyrite, FeS_2. Recovery of sulfur and iron from pyrite concentrates requires crushing and grinding, which results in suspension of fine dusts.[71,152]

3.2.3 Fuel Oil

Fly ash from burning fuel oil* is most commonly about 69,000 to 80,000 μg/m^3 or approximately 2 g/lb of oil fired. The concentration of Fe_2O_3 in the fly ash is about 3.5 percent. This would result in an emission of 50,000 μg of Fe_2O_3 per pound of fuel oil burned. A boiler burning 1,000 pounds of oil per hour would be discharging about 50 g of Fe_2O_3 per hour into the air.[122]

3.3 Product Sources

3.3.1 Incineration

Incineration of municipal wastes may produce some iron pollution in the air. Burning such as this is reported to produce 17 pounds of particulate per ton.[44] Kaiser[67] has averaged the emissions from three incinerators in New York City and found that the collected fly ash contains 6.3 percent iron, while the fly ash passing through the control equipment contains 2.1 percent iron.

3.3.2 Welding Rods

Welding rods contribute some iron pollution to the air. In one study, the dust contained 25 to 30 percent of iron as Fe_3O_4 and gamma-Fe_2O_3.[98]

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*These data are based on residual oil.

3.3.3 Antiknock Compounds

Ferrocene (dicyclopentadienyl iron) and iron carbonyl ($Fe(CO)_5$) have been studied as antiknock agents.[68] Since use of these compounds results in excessive engine deposits, they have not been commercially used as antiknock agents. Rose[106] does not think automobile exhaust emissions are an important source of iron pollution.

3.4 Environmental Air Concentrations

Air quality data obtained from the National Air Sampling Network are shown in Table 9 in the Appendix. The national average concentration in 1964 was 1.58 $\mu g/m^3$ and the national maximum was 22.0 $\mu g/m^3$.[1,3,5,6]

Lee *et al.*[72] determined the particle size distribution of iron particulates from samples collected from ambient air in downtown Cincinnati, Ohio, and Fairfax, a suburb of Cincinnati. The concentrations and mass median diameters were significantly higher in downtown Cincinnati than in suburban Fairfax. The concentrations were 3.12 and 1.15 $\mu g/m^3$ respectively for Cincinnati and Fairfax, and the mass median diameters were 3.7 and 1.4 μ respectively.

4. ABATEMENT

Particulate control for the emission sources should be adequate to remove iron.

4.1 Iron and Steel Industry

Control of emissions from the iron and steel industry is being accomplished through improvements in steel processing.[114,37] In 1955 the basic oxygen process was initiated as an economical process of producing steel. Every basic oxygen furnace constructed in this country has been equipped with control equipment. In 1966, 28 percent of the steel made in the U.S. was refined in these new furnaces. Wheeler[144] anticipates that this method of steel production will soon account for 60 percent or more of total steel production.

Dust removal is accomplished by high-efficiency electrostatic precipitators, venturi type scrubbers,[37] or filters. However, filters have not been used on basic oxygen furnaces in the U.S. Table 10 in the Appendix gives a summary of the relative efficiency of the various types of control equipment. Additional information can be found in the references listed in Table 11 in the Appendix.

The quantity of dust collected averages 35 lb/ton of steel or 35,000 tons/year for two 200-ton furnaces producing 2,000,000 tons of steel per year. Some of this dust (containing about 65 percent iron) is reclaimed by compacting it in a sintering plant or modulizer. Dust which contains a large quantity of zinc oxide (produced from galvanized scrap) cannot be reused.[114]

The cost of fume control is given in Section 5.

5. ECONOMICS

Economic losses due to iron pollution arise from soiling. For example, a Chicago parking lot owner noted that one parking lot was not being used even though it was in a good location. Investigation revealed that cars parked there were being stained by iron particles emitted from a nearby grinding operation. Some cars required repainting because the stains could not be removed by cleaning and polishing. Thus, both the parking lot owner and the automobile owners suffered economic losses due to iron pollution.[49] However, no information has been found on the magnitude of losses resulting from material damage.

The cost of fume control equipment for basic oxygen furnaces ranges between \$3,000,000 and \$7,500,000 and represents 14 to 19 percent of the total plant cost. Operating costs usually range from \$0.15 to \$0.25 per ton of steel, or \$300,000 to \$500,000 per year for a plant with two 200-ton furnaces.[114] The American Iron and Steel Institute has published the Expenditures for Pollution Control in the Iron and Steel Industry as given in Table 12 in the Appendix.

Data on the production and consumption of iron and steel are presented in Section 3.

6. METHODS OF ANALYSIS

6.1 Sampling Methods

Dusts and fumes of iron compounds may be collected by any method suitable for collection of other dusts and fumes; the impinger, electrostatic precipitator, and filter are commonly used. The National Air Sampling Network uses a high volume filtration sampler.[135]

6.2 Quantitative Methods

Emission spectroscopy has been used by the National Air Pollution Control Administration for iron analysis of samples from the National Air Sampling Network.[135,2] The samples are ashed and extracted to eliminate interfering elements. The minimum detectable iron concentration by emission spectroscopy is 0.084 μg/m^3 for urban samples and 0.006 μg/m^3 for nonurban samples. The different sensitivities result from the different extraction procedures required for urban samples.[7]

Thompson _et al_.[135] have reported that the National Air Pollution Control Administration uses atomic absorption to supplement analyses obtained by emission spectroscopy. The method has a minimum detectable limit of 0.01 μg/m^3 based on a 2,000 m^3 air sample.

Atomic absorption spectroscopy has been applied to the analysis of iron in air by Sachdev, Robinson, and West.[108] The sensitivity is 50 μg/m^3 of solution.

A method for determining iron in the ambient air has been described by West _et al_.[143] The dust sample is collected on filter paper with a high volume sampler and analyzed by the ring oven technique, using ferrocyanide. The limit of detection is 0.015 μg, or approximately 2 $\mu g/m^3$.

A flame emission spectrophotometry method for determining mass concentration of Fe_2O_3 aerosol in exposure chambers is reported by Crider, Strong, and Barkley.[35] This is a continuous monitoring system sensitive to 3 μg of Fe_2O_3/m^3. At the 100 to 1,000 $\mu g/m^3$ level, the precision was ±12 percent.

A procedure for determining the iron concentration in plant tissue and soil extracts was set forth by Paul.[95] In this procedure the ferrous ion forms a complex compound with 1,10-phenanthroline, which is then determined colorimetrically.

Strackee[131] has measured the iron content of air by electron spin resonance spectrometry.

Butt _et al_.[29] has recorded an emission spectrographic method for determining the trace metal content (including iron) in the human liver, kidney, lung, brain, spleen, and heart.

Brief _et al_.[23] has described a method for collecting and determining the air concentration of iron pentacarbonyl. The method has a sensitivity of 1μ of iron or 71 $\mu g/m^3$.

Bulba and Silverman[28] have developed a method of producing aerosols of iron oxides. A stream of nitrogen is passed through iron pentacarbonyl, after which it is mixed with an oxygen stream. This mixture is passed through a furnace which causes the oxidation of iron carbonyl to iron oxide.

Mallik and Buddhadev[76] have reported two spot-test methods for the determination of iron. Both methods use phenyl-2-pyridylketoxine with color development with (1) sodium carbonate and (2) ammonia. Interfering ions are copper, cobalt, and cyanide. The limit of identification is about 0.05 μg.

7. SUMMARY AND CONCLUSIONS

Inhalation of iron and iron oxides is known to produce a benign siderosis (or pneumoconiosis). However, in addition to the benign condition, there may be very serious synergistic effects as well as other undesirable effects, such as chronic bronchitis. In the laboratory, iron oxide has been shown to act as a vehicle to transport the carcinogens in high local concentrations to the target tissue. Similarly, sulfur dioxide is transported in high local concentrations deep into the lung by iron oxide particles. The relationships between dose and time and these conditions have not been determined.

No evidence of animal or plant damage was found in this survey.

Soiling of materials by airborne iron or its compounds may produce economic losses. For example, iron particles have been observed to produce stains on automobiles, requiring them to be repainted. Iron oxide particulates may also reduce visibility.

The results from the National Air Sampling Network showed that iron concentrations ranged up to 22 $\mu g/m^3$, with an average of 1.6 $\mu g/m^3$ in 1964. The most likely sources of iron pollution are from the iron and steel industry. The validity of this conclusion has been demonstrated by the decrease in iron concentration during steel strikes as well as by analysis of iron in the stack emissions. The iron pollution may be controlled by particulate removal equipment, such as electrostatic precipitators, venturi scrubbers, and filters.

Air pollution control cost the steel industry approximately $102 million in 1968. Fume control equipment costs for basic oxygen furnaces range between $3 and $7.5 million. This represents 14 to 19 percent of the total plant cost. Operating costs average $0.15 to $0.25 per ton of steel.

Atomic absorption and emission spectroscopy analytical methods are available for the determination of iron in the ambient air.

Based on the material presented in this report, further studies are suggested in the following areas:

(1) The role of iron and its compounds in carcinogenesis, especially at the low concentrations observed in the atmosphere.

(2) The role of iron and its compounds as synergistic agents with other air pollutants (such as sulfur dioxide) from at least two viewpoints-catalytic oxidation of pollutant in air and transport of pollutant into the lungs.

(3) The soiling characteristics of iron and its compounds as related to particle size, concentration, and chemical composition.

REFERENCES

1. Air Pollution Measurements of the National Air Sampling Network, 1953-57, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio (1958).

2. Air Pollution Measurements of the National Air Sampling Network - Analyses of Suspended Particulates, 1957-1961, U.S. Dept. of Health, Education, and Welfare, Public Health Service Publication No. 978, U.S. Government Printing Office, Washington, D.C. (1962).

3. Air Pollution Measurements of the National Air Sampling Network - Analyses of Suspended Particulates, 1963, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio (1965).

4. Air Quality Criteria for Particulate Matter, U.S. Dept. of Health, Education, and Welfare, National Air Pollution Control Administration Publication No. AP-49, U.S. Government Printing Office, Washington, D.C. (1969).

5. Air Quality Data, 1962, National Air Sampling Network, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio.

6. Air Quality Data from the National Air Sampling Networks and Contributing State and Local Networks, 1964-65, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio (1966).

7. Air Quality Data from the National Air Sampling Networks and Contributing State and Local Networks, 1966 ed., U.S. Dept. of Health, Education, and Welfare, National Air Pollution Control Administration Publication No. APTD 68-9, U.S. Government Printing Office, Washington, D.C. (1968).

8. Akashi, S., The Mechanism Producing Metal Fever in the Process of Welding with Low Hydrogen-Type Electrodes, _Japan_. _J_. _Ind_. _Health_ (Tokyo) _3_(4):237 (1967).

9. Albert, R. E., _et al_., "The Clearance of Radioactive Particles from the Human Lung," in _Inhaled Particles and Vapours II_, C. N. Davies, Ed., Proceedings of an International Symposium organized by the British Occupational Hygiene Society, Cambridge, England, Sept. 28-Oct. 1, 1965 (London: Pergamon, pp. 361-378, 1967).

10. Amdur, M. O., and D. Underhill, The Effect of Various Aerosols on the Response of Guinea Pigs to Sulfur Dioxide, Arch. Environ. Health 16:461 (1968).

11. Annual Statistical Report, 1967, American Iron and Steel Institute, New York (1968).

12. Antipin, V. G., Dust Formation in the Melting Chamber of Large-Capacity Open-Hearth Furnaces, Izv. Vuz-Chern. Met. 2:39 (1961).

13. Archer, A., Clean Air and the Iron Foundry, (Part 1) Proc. Intern. Clean Air Congr., London (1966).

14. Atsuta, B., A Radiological Investigation of Silicosis Cases Due to Inhalation of Pyrites Cinder Dust, With Some Consideration on the Influence of SO_2 Gas, Japan. J. Ind. Health (Tokyo) 1(5):39 (1959).

15. Bair, W. J., and J. V. Dilley, "Pulmonary Clearance of $^{59}Fe_2O_3$ and $^{51}Cr_2O_3$ in Rats and Dogs Exposed to Cigarette Smoke," in Inhaled Particles and Vapours II, C. N. Davies (Ed.), Proceedings of an International Symposium organized by the British Occupational Hygiene Society, Cambridge, England, Sept. 28-Oct. 1, 1965 (London: Pergamon, pp. 251-271, 1967).

16. Baum, L., and A. Hahn, Removal of Dust from Electric Furnace Waste Gases. Part I - Experience with Wet Dust Removal by Venturi Scrubbers. Part II - Experience with a Dry Electrostatic Filter on a 100-m Ton Electric Arc Furnace, Stahl Eisen 84(23):1497 (1964).

17. Benz, D. L., and R. Bird, Control of Pollution from Electric Arc Furnaces at Oregon Steel Mills Co., Preprint, 1965.

18. Bergmann, P., et al., Development and Design of a Modern Dust Removal System for an Electric Steel Plant, Text in German. Stahl Eisen 87(22):1310 (1967).

19. Billings, C. E., W. D. Small, and L. Silverman, Pilot-Plant Studies of a Continuous Slag-Wool Filter for Open-Hearth Fume, J. Air Pollution Control Assoc. 5(3):159 (1955).

20. Blaskowski, H. J., and A. J. Sefcik, Economics of Gas Cooling and Gas Cleaning Systems Associated with the BOF Process, Combustion 39(5):31 (1967).

21. Bonser, G. M., J. S. Faulds, and M. J. Stewart, Occupational Cancer of the Urinary Bladder in Dyestuffs Operatives and of the Lung in Asbestos Textile Workers and Iron-Ore Miners, Am. J. Clin. Pathol. 25:126 (1955).

22. Bracewell, J. M. and O. Gall, Catalytic Oxidation of Sulphur Dioxide in Solution at Concentrations Occurring in Fog Droplets, Presented at the Symposium on the Physico-Chemical Transformation of Sulphur Compounds in the Atmosphere and Formation of Acid Smogs, Mainz, Germany (1967).

23. Brief, R. S., R. S. Ajemian, and R. G. Confer, Iron Pentacarbonyl: Its Toxicity, Detection, and Potential for Formation, Am. Ind. Hyg. Assoc. J. 28(1):21 (1967).

24. Brief, R. S., A. H. Rose, Jr., and D. G. Stephen, Properties and Control of Electric-Arc Steel Furnace Fumes, J. Air Pollution Control Assoc. 6(4):220 (1957).

25. Broman, C. U., Scrubbing for Clean Air, Preprint. Presented at the 59th Annual Meeting, Air Pollution Control Association, San Francisco, Calif., Paper No. 66-99 (June 20-24, 1966).

26. Broman, C. U., and R. R. Iseli, The Control of Open-Hearth Stack Emissions with Venturi Type Scrubber, Blast Furnace Steel Plant 56(2):143 (1968).

27. Bruederle, E. U., and G. Urban, Removal of Dust from Electric Waste Gases. Part III - Extraction of Dust from Arc Furnaces by Means of Electrofilters. Part IV - Experience with Drawing off the Waste Gases and with Electrical Dust Extraction on Arc Furnaces, Stahl Eisen 84(23):1500 (1964).

28. Bulba, E., and L. A. Silverman, Recirculating Aerosol Tunnel, Read before the 59th Annual Meeting, Air Pollution Control Association, San Francisco, Calif. (June 23, 1966).

29. Butt, E. M., et al., Use of Emission Spectrograph for Study of Inorganic Elements in Human Tissues, Am. J. Clin. Pathol. 24:385 (1954).

30. Caruso, P., Aspects of the Cooling and Purification of Fumes in the L.D. Steel Plant, Text in Italian. Met. Ital. 49(9):699 (1967).

31. Cholak, J., L. J. Schafer, and D. Yeager, Air Pollution Near an Iron Slag Processing Plant, *Am. Ind. Hyg. Assoc. Quart. 15*:3 (1954).

32. Community Air Quality Guides, *Am. Ind. Hyg. Assoc. J. 29*: 1 (1968).

33. A Compilation of Selected Air Pollution Emission Control Regulations and Ordinances, U.S. Dept. Of Health, Education, and Welfare, Public Health Service Publication No. 999-AP-43 (1968).

34. Contaminant Emissions from Ferrous Jobbing Foundries, (Statutory Authority: Public Health Law, SS 1271, 1276) New York State Air Pollution Control Board, Albany (1968).

35. Crider, W. L., A. A. Strong, and N. P. Barkley, Flame Emission Instrument for Selectively Monitoring Fe_2O_3 Aerosol in Animal Exposure Chambers, Preprint, Public Health Service, Cincinnati, Ohio, National Center for Air Pollution Control (1967).

36. Cuffe, S. T., and R. W. Gerstle, Emissions from Coal-Fired Power Plants: A Comprehensive Summary, Public Health Service Publication No. 999-AP-35 (1967).

37. Danielson, J. A. (Ed.), Air Pollution Engineering Manual, U.S. Department of Health, Education, and Welfare, Public Health Service Publication 999-AP-40 (1967).

38. Davies, E., and W. T. Cosby, "The Control of Fume from Arc Furnaces," in *Fume Arrestment, Special Report 83* (London: Lea, 1964).

39. Demidnnko, N. M., The Effect of Mixed Industrial Dust on the Organism, *Gigiena i Sanit. 11*:26 (1954); Translated by B. S. Levine, *U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 4*:243 (1960).

40. Douglas, I. H., "Direct Fume Extraction and Collection Applied to a Fifteen Ton Arc Furnace," in *Fume Arrestment, Special Report 83* (London: Lea, 1964).

41. Dust Collector - Recirculation of Clean Air, Machinery Market (Johannesburg) 3455:35 (1967).

42. Dust Emission from Induced-Draft Ore-Sintering Installations, VDI (Verein Deutscher Ingenieure) Kommission Reinhaltung der Luft, Duesseldorf, Germany, 2095 (1959).

43. Einbrodt, H. J., and J. Fitzek, Chemical Composition of Dust Deposited in the Lungs and Regional Lymph Nodes of Mine Horses, Text in German. Beitr. Silikose-Forsch. 91:29 (1967).

44. Engdahl, R. B., "Stationary Combustion Sources," in Air Pollution Sources and Their Control, vol. III, 2nd ed. (New York: Academic, 1968).

45. Ertl, D. W., Electrostatic Gas Cleaning, S. African Mech. Engr. (Johannesburg) 16(8):159 (1967).

46. Faulds, J. S., Carcinoma of the Lung in Hematite Workers, J. Pathol. Bacteriol. 72:353 (1956).

47. Fernschild, D., and R. Lohse, Adoption of the Venturi Gas-Cleaning Process by the Iron Metallurgical Industry of East-Germany, Neue Huette 11(10):594 (1966).

48. Ferrari, R., Experiences in Developing an Effective Pollution Control System for a Submerged Arc Ferroalloy Furnace Operation, J. Metals 20(4):95 (1968).

49. Fochtman, E. G., and G. Langer, Automobile Paint Damaged by Airborne Iron Particles, J. Air Pollution Control Assoc. 6(4):243 (1957).

50. Foundry Fume Disappears - Gas Cleaning at Ford's Leamington Plant, Iron and Steel (London) 40(1):8 (1967).

51. Gartner, H., and F. Sommer, Experimental Investigations into the Influence of Dust on the Formation of the Radiographic Image of Pneumoconioses, Text in German. Arch. Hyg. Bakteriol. 151(1-2):29 (1967).

52. Gilli, P. V., and R. Kemmetmueller, Minimizing Dust Problems in BOF Shops, Iron Steel Engr. 43(9):193 (1966).

53. Greaves, M. J., The Effects of Modern Burdens on Blast Furnace Design, J. Metals (Japan) 18(3):378 (1966).

54. Haddow, A., and E. S. Horning, On the Carcinogenicity of an Iron-Dextran Complex, J. Natl. Cancer Inst. 24(109) (1960).

55. Hampel, C. A., Iron - The Encyclopedia of the Chemical Elements, (New York: Reinhold, 1968).

56. Harris, L. S., Scrubbing Characteristics of the Ejector Venturi Scrubber, J. Air Pollution Control Assoc. 13(12): 613 (1963).

57. Henscher, H. C., Wet vs. Dry Gas Cleaning in the Industry, J. Air Pollution Control Assoc. 18(5):338 (1968).

58. Hoff, H., Fundamentals of the Treatment of the Brown Fumes from the Basic Oxygen Process, Stahl Eisen 81(9):562 (1961).

59. Hoff, H., and J. Maatsch, "Converter Waste Gas Cleaning by the 'Minimum Gas' Method at Fried. Krupp," in Fume Arrestment, Special Report 83 (London: Lea, 1964).

60. Hohenberger, A., Dust Removal from Electric Arc Furnaces, Stahl Eisen 81(15):1001 (1961).

61. Holland, M., and K. B. Whitman, "Direct Fume Extraction for Large Arc Furnaces," in Fume Arrestment, Special Report 83 (London: Lea, 1964).

62. How Steel Company of Canada has Battled Against Air and Water Pollution During the Past 40 Years, Air Eng. 9(2):14 (1967).

63. Iron and Steel Producing and Finishing Works of the United States, Table prepared by the American Iron and Steel Institute from the Directory of Iron and Steel Works of the United States and Canada, Personal communication with American Iron and Steel Institute (June 1966).

64. Ironton, Ohio, Ashland, Kentucky, Huntington, West Virginia, Air Pollution Abatement Activity, Pre-Conference Investigations, U.S. Dept. of Health, Education, and Welfare, National Center for Air Pollution Control Publication APTD-68-2 (1968).

65. Jackson, A., "Fume Cleaning in Ajax Furnaces," in Fume Arrestment, Special Report 83 (London: Lea, 1964).

66. Kahnwald, H., and O. Etterich, Determination of the Volume, Composition, and Temperature of the Waste Gas and the Dust During Meltdown and Oxidation by Oxygen Lancing in a 15-Ton Electric Arc Furnace, Stahl Eisen 83(17):1067 (1963).

67. Kaiser, E. R., Refuse Composition and Flue-Gas Analyses from Municipal Incinerators, Proc. Natl. Incinerator Conf., New York City (1964).

68. Kirk-Othmer Encyclopedia of Chemical Technology (New York: Interscience, 1948).

69. Kleinfeld, M., et al., A Clinical, Roentgenological, and Physiological Study of Magnetite Workers, Arch. Environ. Health 16:392 (1968).

70. Kosaka, M., and S. Minowa, Effect of Rate of Carbon Elimination Upon the Formation of Oxide Fumes in the Oxygen Blowing (of Steel), Tetsu To Hagane 50(11):1735 (1964).

71. Kossovskii, E. O., Sanitation of Iron Pyrites Grinding at the M.B. Frunze Sulfuric Acid Plant, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 12:12 (1963).

72. Lee, R. E., Jr., R. K. Patterson, and J. Wagman, Particle-Size Distribution of Metal Components in Urban Air, Environ. Sci. Tech. 2(4):288 (1968).

73. Leonova, Y. I., The Mechanism of Iron Ore Dust Action on Animals and Man, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 3:211 (1960).

74. Limitations of Emissions of Iron Metallurgical Dusts, 1. Procede a l'Oxygene - Convertisseur. Centre Interprofessionnel Technique d'Etudes de la Pollution Atmospherique, Paris, France (1967).

75. Luccioni, R., J. Charpin, and M. Mosinger, Pulmonary Siderosis and Arc Welding, Arch. Maladies Profess. Med. Trav. Securite Sociale (Paris) 27:803 (1966).

76. Mallik, M. L., and S. Buddhadev, Specific Spot Test for Iron, *Anal. Chim. Acta 23*(3):225 (1960).

77. Matsui, K., *et al.*, Studies on the Metal Fume Fever and Pneumoconiosis due to Welding Work in the Holds, Text in Japanese. *Japan. J. Ind. Health* (Tokyo), *7*(11):671 (1965).

78. Mayer, M., A Compilation of Air Pollutant Emission Factors for Combustion Processes, Gasoline Evaporation, and Selected Industrial Processes, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio (1965).

79. Mazina, D. V., Carbon Monoxide Poisoning During Shut-Off of the Burner Blowers of the Air Heaters in Blast Furnaces, Text in Russian. *Gigiena Truda i Prof. Zabolevaniya* (Moscow) *10*(12):54 (1966).

80. Meinshausen, G., Operational Experience with Dust Removal Equipment in Forced Oxygen Steelworks, Text in German. *Stahl Eisen 87*(22):1304 (1967).

81. Meldau, R., Evolution of Fumes from Steel Baths at High Temperatures, *Stahl Eisen 80*(19):1288 (1960).

82. *The Merck Index*, 8th ed. (Rahway, N.J.: Merck, 1968).

83. *Mineral Facts and Problems*, Bureau of Mines, Bulletin 630, U.S. Government Printing Office, Washington, D.C. (1965).

84. *Minerals Yearbook*, Bureau of Mines, U.S. Government Printing Office, Washington, D.C. (1948-1966).

85. Miqawi, M., *et al.*, Effect of Various Factors Upon the Quantity of Brown Fumes Produced in Oxygen Steelmaking, *Izv. Vuz-Chern. Met. 1*:41 (1964).

86. Mitchell, R. T., Dry Electrostatic Precipitators and Waagner-Biro Wet Washing Systems, in *Fume Arrestment, Special Report 83* (London: Lea, 1964).

87. Mole, P. J., Smothering Fumes at Their Source, *Factory 126* (2):138 (1968).

88. Morita, S., Operation and Economy of the Oxygen Converter Gas Recovery Process (OG Process), in Fume Arrestment, Special Report 83 (London: Lea, 1964).

89. Morita, S., et al., Operating Results Obtained in a 130-Ton Basic Oxygen Furnace Equipped with an OG Gas Recovery System, Tetsu To Hagane 49(3):405 (1963).

90. Namy, G., J. Dumond-Fillon, and P. A. Young, Gas Recovery Without Combustion from Oxygen Converters: The Irsid-Cafl Pressure Regulation Process, in Fume Arrestment, Special Report 83 (London: Lea, 1964).

91. Neukomm, S., Evaluation of the Potential Carcinogenic and Co-Carcinogenic Action of Drugs, Oncologia 19:239 (1965).

92. Nishchii, R. A., Oxygen Blast Effect on Air in Electric Steel Smelting Mills, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 5:27 (1961).

93. Pallinger, J., A New Wet Method for Separation of Very Fine Dust, Staub. 22(7):270 (1962).

94. Parker, C. M., BOF Air Cleaning Experiences, J. Air Pollution Control Assoc. 16(8):446 (1966).

95. Paul, J., Simultaneous Determination of Iron and Aluminum in Plant Tissues and Soil Extracts, Mikrochim. Acta 6:1075 (1966).

96. Pendergrass, E. P., and S. S. Leopold, Benign Pneumoconiosis, J. Am. Med. Assoc. 127(12):701 (1945).

97. Perbix, G. W., Thermodynamic Evaluation of Basic Oxygen Furnace Hot Model Studies, J. Metals (Japan) 18(7):824 (1966).

98. Pfefferkorn, G., and H. Desler, Investigating Smokes Generated in Electric-Arc Welding, Staub-Reinhalt Luft 27(8):1 (1967).

99. Pottinger, J. F., The Collection of Difficult Materials by Electrostatic Precipitation, Australian Chem. Process. Eng. (Sidney) 20(2):11 (1967).

100. Potzl, K., and R. Reiter, The Respiratory Tract Model as a Retention Simulator in Practical Use, Zentr. Aerosol-Forsch. (Stuttgart) 13:372 (1967).

101. Pursglove, J., Jr., Fly Ash in 1980, Coal Age 72:84 (1967).

102. Reid, W. T., Basic Problems in the Formation of Sulfates in Boiler Furnaces, J. Eng. Power 89:283 (1967).

103. Rengstorff, G. W. P., A Research Approach to the Control of Emissions from Steelmaking Processes, J. Air Pollution Control Assoc. 13(4):170 (1963).

104. Restricting Dust Emission in Blast-Furnace Operation, VDI (Verein Deutscher Ingenieure) Kommission Reinhaltung der Luft, Duesseldorf, Germany, 2099 (1959).

105. Robinson, E., Effect of the Physical Properties of the Atmosphere, in Air Pollution, I, 2nd ed. (New York: Academic, 1968).

106. Rose, A., U.S. Dept. of Health, Education, and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio, personal communication (Jan. 1969).

107. Roshchin, I. V., The Effect on the Organism of the Aerosol Liberated by the Bessemer Process, Hyg. Sanitation 32(1): 31 (1967).

108. Sachdev, H. L., J. W. Robinson, and P. W. West, Determination of Manganese, Iron, and Nickel in Air and Water by Atomic Absorption Spectroscopy, Anal. Chim. Acta 38:499 (1967).

109. Sadoul, F., et al., La Pneumoconiose des mineurs de fer du bassim de lorraine, Rev. Prat. 8:1505 (1958).

110. Saffiotti, U., F. Cefis, and L. H. Kolb, Bronchogenic Carcinoma Induction by Particulate Carcinogens, Proc. Am. Assoc. Cancer Research 5(1):55 (1964).

111. Saffiotti, U., F. Cefis, and L. H. Kolb, A Method for the Experimental Induction of Bronchogenic Carcinoma, Cancer Research 28(1):104 (1968).

112. Saffiotti, U., *et al*., Experimental Studies of the Conditions of Exposure to Carcinogens for Lung Cancer Induction, *J. Air Pollution Control Assoc*. *15*(1):23 (1965).

113. Schneider, R. L., Engineering, Operation and Maintenance of Electrostatic Precipitators on Open-Hearth Furnaces, *J. Air Pollution Control Assoc*. *13*(8):348 (1963).

114. Schueneman, J. J., M. D. High, and W. E. Bye, Air Pollution Aspects of the Iron and Steel Industry, U.S. Dept. of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio, Division of Air Pollution Publication No. 999-AP-1 (June 1963).

115. Sem, M. O., and F. C. Collins, Fume Problems in Electric Smelting and Contributions to Their Solution, *J. Air Pollution Control Assoc*. *5*(3):157 (1955).

116. Serokhvostov, A. L., *et al*., The Formation of Dust During Oxygen Lancing on the Open-Hearth Steel Bath, *Izv. Vuz-Chern. Met*. *6*:52 (1964).

117. Silverman, L., High Temperature Gas and Aerosol Removal with Fibrous Filters, *Proc. Air Water Pollution Abatement Conf*. (1957).

118. Singhal, R. K., Dust Collection and Gas Cleaning in the Steel Industry - II, *Steel Times* (London) *193*:739 (1966).

119. Smith, B. M., J. Wagman, and B. R. Fish, Interaction of Airborne Particles with Gases, *Environ. Sci. Tech*. *3*(6):558 (1969).

120. Smith, B. M., R. L. Walker, and L. E. Stettler, Interaction of Airborne Vapors with Particulates, Health Physics Div. Annual Progress Report for Period Ending July 31, 1967, Oak Ridge National Lab., Tenn.

121. Smith, W. M., and D. W. Coy, Collection of Iron Oxide Fumes with an Electrostatic Precipitator, *Blast Furnace Steel Plant* *54*(9):830 (1966).

122. Smith, W. S., Atmospheric Emissions from Fuel Oil Combustion - An Inventory Guide, U.S. Dept. of Health, Education, and Welfare, Public Health Service Publication No. 999-AP-2 U.S. Government Printing Office, Washington, D.C. (1962).

123. Smith, W. S., and C. W. Gruber, Atmospheric Emissions from Coal Combustion - An Inventory Guide, U.S. Dept. of Health, Education, and Welfare, Public Health Service Publication No. 999-AP-24, U.S. Government Printing Office, Washington, D.C. (1966).

124. Snowball, A. F., Development of an Air Pollution Program at Cominco's Kimberley Operation, J. Air Pollution Control Assoc. 16(2):59 (1966).

125. Spaite, P. W., D. G. Stephen, and A. H. Rose, Jr., High Temperature Fabric Filtration of Industrial Gases, J. Air Pollution Control Assoc. 11:243 (1961).

126. Steel Industry Pushes Fight on Pollution, Steel Facts 203: 5 (1968).

127. Sterling, M., Current Status and Future Prospects - Foundry Air Pollution Control, Proc. Natl. Conf. Air Pollution, 3rd, Washington, D.C. (1966).

128. Stokinger, H. E., "Iron," in Industrial Hygiene and Toxicology, vol. II, F. A. Patty, Ed. (New York: Interscience, p.871, 1963).

129. Stokinger, H. E., and D. L. Coffin, "Biological Effects of Air Pollutants," in Air Pollution, I, (New York: Academic, 1968).

130. Storch, O., A New Venturi Scrubber to Separate Dust Particles Less than 1 Micron, Especially of Brown Smoke, Staub. (English Translation) 26(11):32 (1966).

131. Strackee, L., Electron Spin Resonance of Ferromagnetic Particles in Air-borne Dust, Nature 218:497 (1968).

132. Tabor, E. C., and J. E. Meeker, Effects of the 1956 Steel Strike on Air Pollution Levels in Several Communities, Proc. Air Pollution Control Assoc., 51st, Philadelphia, Pa. (1958).

133. Tailor, J. P., The Study of the CVX Wet Gas Scrubber in Its Application on Power Stations, Foundries, and Iron Ore Mills, Preprint (1967).

134. Thom, G. W., and A. F. Schuldt, The Collection of Open-Hearth Dust and Its Reclamation Using the SL/RN Process, Can. Mining Met. Bull. 59(654):1229 (1966).

135. Thompson, R. J., G. B. Morgan, and L. J. Purdue, Analyses of Selected Elements in Atmospheric Particulate Matter by Atomic Absorption, Preprint, presented at the Instrument Society of America Symposium, New Orleans, La. (May 5-7, 1969).

136. Threshold Limit Values for 1967, Adopted at the 29th Annual Meeting of the American Conference of Governmental Industrial Hygienists, Chicago, Ill. (May 1-2, 1967).

137. Tomita, A., S. Tamamoto, and K. Iwase, Equipment and Operation of a Basic Oxygen LD Steelmaking Plant at the Wakayama (Japan) Works, Tetsu To Hagane 50(3)393 (1964).

138. Tulcinsky, S., and A. Lemaire, Cooling and Scrubbing of Smoke Emitted by LD Steel Converters in Sidmar Ironworks, Rev. Met. (Paris) 63(9):659 (1966).

139. Ussleber, K., Design of a Hot-Blast Cupola Plant with a Wet Electrostatic Precipitator for Cleaning the Stack Gas, Giesserei 52(7):194 (1965).

140. Vincent, E., and J. McGinnity, National Air Pollution Control Administration, personal communication (June 1969).

141. Walker, A. W., and R. M. Hall, Operating Experience with a Flooded Disc Scrubber - A New Variable Throat Orifice Contractor, J. Air Pollution Control Assoc. 18(5):319 (1968).

142. Walsh, J. R., and J. B. Gillick, Iron Chelation in Acute Iron Poisoning and Chronic Hypersiderosis, Clin. Pediat. 4(11):633 (1965).

143. West, P. W., et al., Transfer, Concentration, and Analysis of Collected Air-borne Particulates Based on Ring Oven Techniques, Anal. Chem. 32:943 (1960).

144. Wheeler, D. H., Fume Control in LD Plants, J. Air Pollution Control Assoc. 18:98 (1968).

145. White, H. J., Effect of Fly Ash Characteristics on Collector Performance, Air Repair 5(1):37 (1955).

146. Wilkinson, F. M., Wet Washing of BOF Gases - Lackawanna, Preprint, Bethlehem Steel Corp., Lackawanna Plant, New York (1966).

147. Willett, H. P., Cutting Air Pollution Control Costs, Chem. Eng. Progr. 63(3):80 (1967).

148. Woehlbier, F. H., and G. W. P. Rengstorff, Preliminary Study of Gas Formation During Blast-Furnace Slag Granulation with Water, Preprint, Battelle Memorial Inst., Columbus, Ohio (1968).

149. Wright, R. J., Concepts of Electric Arc Furnace Fume Control, J. Air Pollution Control Assoc. 18(3):175 (1968).

150. Yokomiyo, K., Air Pollution Prevention Equipment Installed in Muroran Steel and Iron Works, Ltd., Clean Air Heat Management (Tokyo) 15(7):19 (1966).

151. Zimmer, K. O., Dust Laden Waste Gases Emitted in the Basic Open-Hearth Process with Usual Melting Practice and with Oxygen Injection; Also Removal of Dust from Them, Stahl Eisen 84(17):1070 (1964).

152. Zimmerman, R. E., and G. H. Roman, Recovering Sulphur and Iron from Coal Pyrites, Coal Age 72(4):60 (1967).

OTHER REFERENCES

Albert, R. E., et al., The Deposition and Clearance of Radioactive Particles in the Human Lung, Arch. Environ. Health 14 (1):10 (1967).

Altybaev, M., and V. V. Streltsov, Removal of Sulphur Compounds from Gaseous Fuels, Coke Chem. (USSR) (English Transl.) (1966).

Ball, R. J., F. D. Muschett, and H. A. Panofsky, Air Pollution at Johnstown, Pennsylvania, (Final Rept. April 1, 1963-March 1967) Pennsylvania State Univ., University Park, Dept. of Meteorology (March 31, 1967).

Barrett, R. E., High-Temperature Corrosion Studies in an Oiled-Fired Laboratory Combustor, Preprint. Presented at the Winter Annual Meeting, American Society of Mechanical Engineers, New York City (Nov. 27-Dec. 1, 1966).

Barrett, R. E., J. D. Hummell, and W. T. Reid, Formation of SO_3 in a Noncatalytic Combustor, J. Eng. Power, p. 7 (1965).

Benforado, D., Control by Incineration, Proc. MECAR Symp., New Developments in Air Pollution Control, Metropolitan Engineers Council on Air Resources, New York City, p. 99 (Oct. 23, 1967).

Bienstock, D., et al., Sulfur Dioxide--Its Chemistry and Removal from Industrial Waste Gases, Bureau of Mines, Washington, D.C., Information Circular 7836 (1958).

Bogdandy, L., Vaporization and Refining. Part II-A of the Kinetics of Iron and Steelmaking Reactions, Arch. Eisenhuettenw. 32(5):287 (1961).

Bulba, E., and L. Silverman, A Mass Recording Stack Monitoring System for Particulates, Preprint. Presented at the 58th Annual Meeting, Air Pollution Control Association, Toronto, Canada. Paper No. 65-141 (June 20-24, 1965).

Casarett, L. J., and B. Epstein, Deposition and Fate of Inhaled Iron-59 Oxide in Rats, Am. Ind. Hyg. Assoc. J. 27(6):533 (1966).

Chambers, L. A., M. J. Foter, and J. Cholak, A Comparison of Particulate Loadings in the Atmospheres of Certain American Cities, Proc. Natl. Air Pollution Symp., 3rd, Pasadena, Calif. (1955).

Chittawadgi, B. S., and A. N. Voinov, Mechanism of Action of Ferrocene on Smoke Reduction in Diffusion Flames, Indian J. Technol. (India) 3(7):209 (1965).

Cholak, J., The Nature of Atmospheric Pollution in a Number of Industrial Communities, Proc. Natl. Air Pollution Symp., 2nd, Pasadena, Calif. (1952).

Committee on Air Pollution Interim Report, Committee on Air Pollution, London, England (1953).

Crider, W. L., N. P. Barkley, and A. A. Strong, Dry-Powder Aerosol Dispersing Device with Long-Time Output Stability, Sci. Instr. 39(2):152 (1968).

Documentation of Threshold Limit Values, American Conference of Governmental Industrial Hygienists Cincinnati, Ohio (1962).

A Feasibility Study of the Recovery of Sulfur and Iron from Coal Pyrites, (Chicago: Weir, 1966).

Finfer, E. Z., Fuel Oil Additives for Controlling Air Contaminant Emissions, J. Air Pollution Control Assoc. 17(1):43 (1967).

Haagen-Smit, A. J., Reactions of Sulfur Dioxide and Other Air Contaminants in the Atmosphere, Proc. Am. Power Conf. 26:117 (1964).

Hebley, H. F., The Control of Gob Pile Fires, J. Air Pollution Control Assoc., 6(1):29 (1956).

Hofer, L. J. E., P. Gusey, and R. B. Anderson, Specificity of Catalysts for the Oxidation of Carbon Monoxide Ethylene Mixtures, J. Catalysis 3:451 (1964).

Hull, H. M., and F. W. Went, Life Processes of Plants as Affected by Air Pollution, Proc. Natl. Air Pollution Symp., 2nd, Pasadena, Calif. (1952).

Industrial Air Pollution Control, Heating, Piping, Air Conditioning 39(3):179 (1967).

Inouye, K., The Role of Copper (II) in the Oxidation of Ferrous Hydroxide Colloid with Special Reference to the Corrosion of Iron in an SO_2-Containing Environment, J. Colloid Interface Sci. 27(2):171 (1968).

Jutze, G. A., R. L. Harris, Jr., and M. Georgevich, The Interstate Air Pollution Surveillance Program (Effects Network), J. Air Pollution Control Assoc. 17(5):291 (1967).

Kaiser, E. R., Composition and Combustion of Refuse, Proc. MECAR Symp., Incineration of Solid Wastes, New York City, p. 1 (1967).

Kalyuzhniy, D. N., Sanitary Protection Against Air Pollution by Waste Products from Ferrous Metallurgical Enterprises, (Transl. as JPRS No. 17, 984), p. 166 (1963).

Katz, M., Sources of Pollution, Proc. Natl. Air Pollution Symp., 2nd, Pasadena, Calif. (1952).

Kerns, B. A., Chemical Suppression of Nitrogen Oxides, Westinghouse Electric Corp., Pittsburgh, Pa., Headquarters Manuf. Lab. (1964).

Kodama, I., Air Pollution in Kanagawa Prefecture, Japan. Air Cleaning Assoc. (Tokyo) 4(2):23 (1967).

Konno, K., Air Filter (3) Japan. Air Cleaning Assoc. (Tokyo) 2(2):35 (1964).

Krueger, A. P., S. Kotaka, and P. C. Andriese, A Study of the Mechanism of Air-Ion-Induced Growth Stimulation in Hordeum Vulgaris, Intern. J. Biometeorol. 7(1):17 (1963).

Krueger, A. P., S. Kotaka, and P. C. Andriese, Studies on Air-Ion-Enhanced Iron Chlorosis. I. Active and Residual Iron, Intern. J. Biometeorol. 8(1):5 (1964).

Levy, A., and E. L. Merryman, Interactions in Sulphur Oxide-Iron Oxide Systems, J. Eng. Power 89A(2):297 (1967).

Lodwick, J. R., Chemical Additives in Petroleum Fuels: Some Uses and Action Mechanisms, J. Inst. Petrol. (London) 50(491):297 (1964).

Louw, C. W. and E. C. Halliday, First Report on Atmospheric Oxidant Measurements in the Towns of Pretoria, Durban and Johannesburg, S. African Ind. Chemist. 18(11):218 (1963).

Mackenzie, R. C., and R. Meldau, The Morphology of Finely-Particular Oxides and Hydroxides of Iron, Aluminium and Manganese, Staub. (English Transl.) 27(5):19 (1967).

Matsufuji, H., Air Pollution of Work Area Due to Dust Particles and Its Prevention, Clean Air (Tokyo), 3(6):52 (1966).

McCune, D. C., A. E. Hitchcock, and L. H. Weinstein, Effect of Mineral Nutrition on the Growth and HF Sensitivity of Gladiolus, Contrib. Boyce Thompson Inst. 23:295 (1966).

Morrow, P. E., Adaptations of the Respiratory Tract to Air Pollutants, Arch. Environ. Health 14(1):127 (1967).

Nader, J. S., Problems and Developments in Monitoring Air Pollution Sources, Preprint, Public Health Service, Cincinnati, Ohio, National Center for Air Pollution Control (1967).

Nagelschmidt, G., The Study of Lung Dust in Pneumoconiosis, Am. Ind. Hyg. Assoc. J. 26:1 (1965).

Ohnira, T., Chemical Property of Dusts and Soot from Furnaces for Cast Iron, Clean Air (Tokyo) 4(3):68 (1966).

Otani, N., et al., Studies on Atmospheric Corrosion of Metals and Anti-Corrosive Coatings in Japan (7th Report). Result of Weathering Test Conducted on Protective Coatings for Five Years. Boshoku Gijutsu (Tokyo) 16(11):23 (1967).

Parkes, W. B., Measurement of Airborne Dust Concentrations in Foundries, Am. Ind. Hyg. Assoc. J. 25(5):447 (1964).

Pertinent Characteristics of the Iron and Steel Industry as Related to Area Redevelopment, Dept. of Commerce, Washington, D.C. (1964).

Petrova, A., Y. Dalakmanski, and D. Bakalov, Study of Contamination of the Atmosphere by Injurious Road (Transport and Industrial Products), J. Hyg. Epidemiol., Microbiol., Immunol. (Prague) 10:383 (1966).

Pfefferkorn, G., and H. Desler, Investigating Smokes Generated in Electric-Arc Welding, Staub. (English Transl.) 27(8):1 (1967).

Potzl, K., Trace Analysis of Calcium in Dusts and Aerosols, Text in German. Naturwissenschaften (Berlin) 53(3):79 (1966).

Potzl, K., Methods for Analysis of Inorganic Aerosols and Their Application to the Investigation of Industrial Dusts, Zentr. Aerosol-Forsch. (Stuttgart) 13(5/6):382 (1967).

Prasad, A. S., Trace Elements in Nutrition: Zinc, Iron, Chromium, Federation Proc. 25:172 (1967).

Pretorius, S. T., and W. G. Mandersloot, The Removal of Air Pollutants from Gases by Reaction with Particulate Solids, Powder Technol. (Amsterdam) 1(3):129 (1967).

Raviolo, V. G., Automotive Trends in a Changing Market, Proc. Am. Petrol. Inst., Sect. III 41:114 (1961).

Reid, W. T., Formation of Alkali Iron Sulfates and Other Compounds Causing Corrosion in Boilers and Gas Turbines, Battelle Memorial Inst., Columbus, Ohio (1966).

The Rising Costs, Machine Design 39(17):23 (1967).

Saffiotti, U., *et al.*, Retention Rates of Particulate Carcinogens in the Lungs, Chicago Med. School Quart. 24(2):10 (1964).

Saruta, N., Air Pollution in Northern Kyushu, Japan. Air Cleaning Assoc. (Tokyo) 4(2):35 (1966).

Sebesta, W., "Ferrous Metallurgical Processes," Chapter 33 in Air Pollution - Sources and Their Control, vol. III, 2nd ed., A. C. Stern, Ed. (New York: Academic, 1968).

Smith, N. J., and R. P. Tessner, The Analysis of Trace Metals in Biological Specimens by a Direct Reading Spectrometric Technique, Preprint, Dow Chemical Co., Midland, Mich., Chemical Physics Research Lab. (1966).

Spenceley, G. D., The Role of Oxygen-Fuel Burners in Scrap Consuming Steel-Making Processes and Their Effect on Fume Emission, Proceedings of the Clean Air Conference, National Society for Clean Air, London (1967).

Stanescu, D. B., *et al.*, Aspects of Pulmonary Mechanics in Arc Welders' Siderosis, Brit. J. Ind. Med. (London) 24(2):143 (1967).

Stein, K. C., _et al._, Catalytic Oxidation of Hydrocarbons (Tests of Single Oxides and Supported Catalysts in a Microcatalytic Reactor), Bureau of Mines, Washington, D.C., Bulletin No. 608 (1963).

Tanaka, S., and J. Lieben, Community Chest X-Rays for Pneumoconiosis Prevention, _Arch. Environ. Health_ _12_:10 (1966).

Tanimura, H., Benzo(a)pyrene in an Iron and Steel Works, _Arch. Environ. Health_ _17_:172 (1968).

Taylor, W. G., _et al._, Reducing Smoke from Gas Turbines, _Mech. Eng._ _90_(7):29 (1968).

Toishi, K., and T. Kenjo, Alkaline Material Liberated Into Atmosphere from New Concrete, _J. Paint Technol._ _39_(506):152 (1967).

Toxicity of Aromatic Hydrocarbons in the Lung, American Petroleum Institute Research Project MC-6, (Progress Rept. for Nov. 1, 1962-Oct. 31, 1963 and program for 1964), Chicago Medical School, Chicago, Ill., Inst. of Medical Research (1963).

Van Beukering, J. A., The Occurrence of Pneumonia Among Miners in an Iron Mine and a Manganese Ore Mine in South Africa, _Ned. Tydschr. Geneesk_ _110_(10):473 (1966); Translated from Dutch, Joint Publications Research Service, Washington, D.C., R-9047-D (1968).

Walker, F. E., and F. E. Hartner, Forms of Sulphur in U.S. Coals, U.S. Bureau of Mines, Washington, D.C., Information Circular 8301 (1966).

Washington, D.C., Metropolitan Area Air Pollution Abatement Activity, Public Health Service, Cincinnati, Ohio, National Center for Air Pollution Control (1967).

Williams, J. D., _et al._, Interstate Air Pollution Study, Phase II, Project Report. VI. Effects of Air Pollution, Public Health Service, Cincinnati, Ohio, National Center for Air Pollution Control (1966).

Yocom, J. E., The Deterioration of Materials in Polluted Atmospheres, _J. Air Pollution Control Assoc._ _8_(3):203 (1958).

Zenz, C., J. P. Bartlett, and W. H. Thiede, Analysis of Ventilation in Older Workers in Foundry, Machine Shop, and Office, _J. Occupational Med._ _7_(9):443 (1965).

APPENDIX

TABLE 3

CRUDE IRON ORE MINED IN THE UNITED STATES BY DISTRICTS, STATES, AND MINING METHODS[84]

(Thousand long tons and exclusive of ore containing 5 percent or more manganese)

District and State	1965			1966		
	Open Pit	Under-ground	Total	Open Pit	Under-ground	Total
Lake Superior						
Michigan	17,342	6,562	23,904	18,248	6,572	24,820
Minnesota	112,664	1,263	113,927	114,851	1,227	116,078
Wisconsin		56	56			
Total	130,006	7,881	137,887	133,099	7,799	140,898
Southeastern States						
Alabama	3,444	659	4,103	3,390	778	4,168
Georgia	1,697		1,697	1,645		1,645
Total	5,141	659	5,800	5,035	778	5,813
Northeastern States						
New Jersey, New York, Pennsylvania . .	*	*	12,206	*	*	11,355
Western States						
Arizona	*		*	*		*
California	*		*	*		*
Colorado	115		115	163		163
Idaho	*		*	*		*
Mississippi	*		*	*		*
Missouri	299	2,532	2,831	264	2,605	2,869
Montana	9		9	12		12
Nevada	*	*	1,301	*	*	1,224
New Mexico	17		17	15		15
Texas	*		*	*		*
Utah	2,303		2,303	2,064		2,064
Wyoming	3,720	815	4,535	4,265	742	5,007
Undistributed	*	*	10,937	*	*	12,959
Total	*	*	22,048	*	*	24,313
Grand Total	160,355	17,586	177,941	164,165	18,214	182,379

*Withheld to avoid disclosing individual confidential data; included with "Undistributed."

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63]

State & City	County	Company	Major Furnaces	Grades of Steel*
ALABAMA				
Birmingham	Jefferson	American Cast Iron Pipe Co. American Steel Pipe Div.		CA
"	"	H. K. Porter Co., Inc. Connors Steel Div.	Elec.	CA
"	"	Republic Steel Corp.	Coke-B/F	
"	"	Southern Electric Steel Co.	Elec.	C
"	"	United States Pipe & Foundry Co.	B/F	
Dothan	Houston	Southern Fabricating Co., Inc. Dixie Tube & Steel, Inc.		C
Fairfield	Jefferson	United States Steel Corp. Sheet & Tin Products Oprs.	Coke-B/F-OH-Bess	CA
Gadsden	Etowah	Republic Steel Corp.	Coke-B/F-Bop-Elec	CA
Haleyville	Winston	Formed Tubes Southern, Inc.		C
No. Birmingham	Jefferson	Southeastern Metals Co., Inc.		C
" "	"	United States Pipe & Foundry	Coke-B/F	
Sheffield	Colbert	Southern Fabricating Co., Inc.		C
Woodward	Jefferson	Woodward Corp.	Coke-B/F	
ARIZONA				
Tempe	Maricopa	Allison Steel Mfg. Co. Rolling Mill Div.	Elec.	C
ARKANSAS				
Magnolia	Columbia	Kalmar Steel Corp.	Elec.	C
CALIFORNIA				
Azusa	Los Angeles	Metalcraft Products Co.		C
"	" "	Southern Pipe & Casing Co.		C
City Industry	" "	Techalloy Co., Inc.		C
Emeryville	Alameda	Judson Steel Corp.	OH	C
Etiwanda	San Bernardino	Etiwanda Steel Products, Inc.	Elec.	CA
Fontana	" "	Kaiser Steel Corp.	Coke-B/F-OH-Bop	CA

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
CALIFORNIA (Cont'd.)				
Hayward	Alameda	Davis Wire Corp.		C
Long Beach	Los Angeles	Soule Steel Co.	Elec.	C
Los Angeles	" "	Bethlehem Steel Corp.	Elec.	CA
" "	" "	California Steel & Tube		C
" "	" "	Calstrip Steel Corp. (Washington Steel Corp.)		CAS
" "	" "	Davis Wire & Cable Corp., K.H.		C
" "	" "	Harris Tube, Inc.		C
" "	" "	Jones & Laughlin Steel Corp. Stainless & Strip Div.		CA
" "	" "	National-Standard Co.		C
" "	" "	Pacific Tube Co.		CAS
" "	" "	Pittsburgh Steel Co. Johnson Steel & Wire Co.,Inc.		C
" "	" "	Republic Steel Corp.		C
" "	" "	Bliss & Laughlin Steel Co.		C
" "	" "	Southwest Steel Rolling Mills	Elec.	C
Napa	Napa	Kaiser Steel Corp.		C
Perris	Riverside	Techalloy Co., Inc.		C
Pittsburg	Contra Costa	United States Steel Corp. Sheet & Tin Products Oprs.		C
So. San Francisco	San Mateo	Bethlehem Steel Corp.		C
" " "	"	Edwards Co., E. H.		C
Torrance	Los Angeles	Armco Steel Corp. National Supply Div.	Elec.	CAS
"	" "	United States Steel Corp. Sheet & Tin Products Oprs.	OH	CA
"	" "	Cal-Metal Corp.		C
Union City	Alameda	Columbia Steel & Shafting Co. (Columbia-Summerill)		CA
" "	"	Pacific States Steel Corp.	OH	CA

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
COLORADO				
Pueblo	Pueblo	CF&I Steel Corp.	Coke-B/F-OH-Bop	CA
Fort Collins	Larimer	Southwest Pipe, Inc.		C
CONNECTICUT				
Branford	New Haven	Atlantic Wire Co.		C
Bridgeport	Fairfield	Carpenter Steel Co., New England Div.	Elec.	CAS
"	"	Heppenstall Co.		C
Bristol	Hartford	Wallace Barnes Steel Div.		CA
E. Hartford	"	Republic Steel Corp.		C
Georgetown	Fairfield	Gilbert & Bennett Mfg. Co.,Inc.		C
New Britain	Hartford	Stanley Works		C
New Haven	New Haven	Detroit Steel Corp.		C
" "	" "	United States Steel Corp. Wire Products Operations		C
Putnam	Windham	Screw and Bolt Corp. Of America Wyckoff Steel Div.		C
Shelton	Fairfield	Driscoll Wire Co.		C
Wallingford	New Haven	Allegheny Ludlum Steel Corp. Wallingford Steel Co.		CAS
"	" "	Ulbrich Stainless Steels, Inc.		S
Willimantic	Windham	Jones & Laughlin Steel Corp.		C
DELAWARE				
Claymont	New Castle	Phoenix Steel Corp.	OH	CA
FLORIDA				
Jacksonville	Duval	Mid-States Steel & Wire Co.		C
"	"	Ivy Steel & Wire Co.		C
Tampa	Hillsborough	Florida Steel Corp.	Elec.	C

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
GEORGIA				
Atlanta	Fulton	Atlantic Steel Co.	Elec.	CA
Hartwell	Hart	Monroe Auto Equipment Co.		C
Norcross	Gwinnett	Tull Allied Metal Products Co.		C
Tallapoosa	Haralson	Atlantic Steel Co.		
		Dixisteel Buildings, Inc.		CA
HAWAII				
Ewa	Honolulu	Hawaiian Western Steel Ltd.	Elec.	C
ILLINOIS				
Alton	Madison	Laclede Steel Co.	Elec.	C
Blue Island	Cook	Enterprise Wire Co.		C
" "	"	Gilbert & Bennett Mfg. Co., Inc.		C
Chicago	"	Borg-Warner Corp.		
		Ingersoll Products Div.		CA
"	"	Chicago Steel & Wire Co.		C
"	"	Finkl & Sons Co., A.	Elec.	CA
"	"	Interlake Steel Corp.	Coke-B/F	
"	"	Naylor Pipe Co.		C
"	"	Regal Tube Co. (Lear-Siegler, Inc.)		C
"	"	Valley Mould & Iron Corp.		
"	"	Wilson Steel & Wire Co.		C
"	"	Wire Sales Co.		C
"	"	Screw and Bolt Corp. of America		
		Wyckoff Steel Div.		C
Chicago Heights	"	Alco Products, Inc.		C
" "	"	Borg-Warner Corp.		
		Calumet Steel Div.	Elec.	C
" "	"	Columbia Tool Steel Co.	Elec.	A
" "	"	Inland Steel Co.		C

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
ILLINOIS (Cont'd.)				
Cicero	Cook	Taylor Forge & Pipe Works		C
"	"	Corey Steel Co.		CS
Dixon	Lee	National-Standard Co.		C
Evanston	Cook	Mark & Co., Clayton		C
Fairbury	Livingston	International Tube Corp.		C
Franklin Park	Cook	Nelsen Steel & Wire Co.		CA
" "	"	Thompson Wire Co.		C
Granite City	Madison	Granite City Steel Co.	Coke-B/F-OH-Bop	CA
Harvey	Cook	Bliss & Laughlin Steel Co.		CA
Joliet	Will	Phoenix Manufacturing Co. Div. Union Tank Car Co.		C
"	"	United States Steel Corp. Wire Products Oprs.		CAS
Kankakee	Kankakee	Kankakee Electric Steel Co.	Elec.	C
Lemont	Will	Ceco Corp. Lemont Mfg. Corp.	Elec.	C
Madison	Madison	Laclede Steel Co.		C
Morton Grove	Cook	Harper Co., H. M.	Elec.	S
Peoria	Peoria	Keystone Consolidated Industries	OH	CA
Riverdale	Cook	Interlake Steel Corp.	Bop	C
South Chicago	Cook	Republic Steel Corp.	Coke-B/F-OH-Elec.	CA
" "	"	United States Steel Corp. Heavy Products Oprs.	B/F-OH-Bess-Elec.	CAS
" "	"	International Harvester Co. Wisconsin Steel Div.	Coke-B/F-Bop	CA
Sterling	Whiteside	Northwestern Steel & Wire Co.	Elec.	C
Union	McHenry	Techalloy Co., Inc.		C
Waukegan	Lake	United States Steel Corp. Wire Products Oprs.		C

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
INDIANA				
West Chester Twp.	Porter	Bethlehem Steel Corp.		CA
Crawfordsville	Montgomery	Mid-States Steel & Wire Co.		C
East Chicago	Lake	Inland Steel Co.	Coke-B/F-OH-Bop	CA
East Chicago	Lake	Youngstown Sheet and Tube Co.	Coke-B/F-OH	CA
Fort Wayne	Allen	Joslyn Stainless Steels Div.	Elec.	S
Gary	Lake	Republic Steel Corp.		CA
"	"	Taylor Forge & Pipe Works		C
"	"	United States Steel Corp.		
		Heavy Products Oprs.	Coke-B/F-OH-Bop	CAS
		Sheet and Tin Products Oprs.		
		Tubular Products Oprs.		
"	"	Western Cold Drawn Steel		CA
Hammond	"	Jones & Laughlin Steel Corp.		C
"	"	La Salle Steel Co.		CA
Indiana Harbor	"	Standard Alliance Industries, Inc.		
		Standard Forgings Div.		CAS
Indianapolis	Marion	Jones & Laughlin Steel Corp.		
		Stainless & Strip Div.		CA
Kokomo	Howard	Continental Steel Corp.	OH-Elec.	C
Muncie	Delaware	Indiana Steel & Wire Co.		C
New Castle	Henry	Borg-Warner Corp.		
		Ingersoll Steel Div.	Elec.	CAS
Portage	Porter	National Steel Corp.		
		Midwest Steel Div.		C
IOWA				
Clinton	Clinton	Central Steel Tube Co.		C
KENTUCKY				
Ashland	Boyd	Armco Steel Corp.	B/F-OH-Bop	CA
Coalton	"	Kentucky Electric Steel Co.	Elec.	C

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
KENTUCKY (Cont'd.)				
Cynthiana	Harrison	Bundy Corp.		C
Henderson	Henderson	Atlas Tack Corp.		C
Wilder	Campbell	Interlake Steel Corp.	Elec.	CA
Owensboro	Davies	Green River Steel Corp. (Jessop Steel Co.)	Elec.	CAS
LOUISIANA				
Baton Rouge	E. Baton Rouge	Stupp Corporation		C
MARYLAND				
Baltimore	Baltimore	Armco Steel Corp.	Elec.	CAS
"	"	Eastern Stainless Steel Corp.	Elec.	AS
"	"	Reid-Avery Co., Inc.		C
Cockeysville	"	Maryland Specialty Wire, Inc.		AS
Cumberland	Allegheany	Cumberland Steel Co.		C
Sparrows Point	Baltimore	Bethlehem Steel Corp.	Coke-B/F-OH-Bop	CA
" "	"	Thompson Wire Co.		C
MASSACHUSETTS				
Boston	Suffolk	Thompson Wire Co.		C
Fairhaven	Bristol	Atlas Tack Corp.		C
Mansfield	Bristol	Bliss & Laughlin Steel Co.		CA
Medford	Suffolk	Northern Steel, Inc.		C
Millbury	Worcester	New England High Carbon Wire Corp.		C
New Bedford	Bristol	Rodney Metals, Inc.		CAS
Palmer	Hampden	CF&I Steel Corp.		C
Readville	Suffolk	Compressed Steel Shafting Co.		C

(continued)

APPENDIX

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
MASSACHUSETTS				
Worcester	Worcester	National-Standard Co.		C
"	"	Pittsburgh Steel Co. Johnson Steel & Wire Co.,Inc.		C
"	"	Thompson Wire Co.		C
"	"	United States Steel Corp. Wire Products Oprs.		C
"	"	Wright Steel & Wire Co., G. F.		C
MICHIGAN				
Dearborn	Wayne	Ford Motor Co.	Coke-B/F-Bop	CA
"	"	Sharon Steel Corp.		CS
Detroit	"	Barry Universal Corp.		C
"	"	Bliss & Laughlin Steel Co.		CA
"	"	Bundy Tubing Co.		C
"	"	Detroit Steel Corp.		C
"	"	Hercules Drawn Steel Corp.		CA
"	"	Lear Siegler, Inc.		C
"	"	McLouth Steel Corp.		CAS
"	"	Plymouth Steel Corp.		C
"	"	Production Steel Strip Corp.		CA
"	"	Standard Tube Co. (Michigan Seamless Tube Co.)		C
Ecorse	"	National Steel Corp. Great Lakes Steel Corp.	OH-Bop-Elec.	CA
Ferndale	"	Allegheny Ludlum Steel Corp.	Elec.	CAS
"	"	Greer Steel Co.		C
"	"	Republic Steel Corp.		C
Gibraltar	"	McLouth Steel Corp.		C
Jackson	Jackson	Walker Mfg. Co.		CAS

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
MICHIGAN				
Ludington	Mason	Motyka Metal Products Tubing Div., Inc.		C
Madison Heights	Oakland	James Steel & Tube Co.		C
Niles	Berrien	National-Standard Co.		C
Plymouth	Wayne	Screw and Bolt Corp. of America Pilgrim Drawn Works (Wyckoff Steel Div.)		C
River Rouge	"	National Steel Corp. Great Lakes Steel Corp.	Coke-B/F	
South Lyon	Oakland	Michigan Seamless Tube Co.		CAS
Sturgis	St. Joseph	Formed Tubes, Inc.		C
Trenton	Wayne	McLouth Steel Corp.	B/F-Elec.-Bop	CAS
Warren (Detroit)	Macomb	Jones & Laughlin Steel Corp. Stainless & Strip Div.	Elec.	CAS
MINNESOTA				
Duluth	St. Louis	United States Steel Corp. Wire Products Oprs.	Coke-B/F-OH	CA
St. Paul	Ramsey	North Star Steel Co.	Elec.	CA
MISSISSIPPI				
Aberdeen	Monroe	Walker Mfg. Co.		CAS
Flowood	Jackson	Mississippi Steel Corp.	Elec.	C
Biloxi	Harrison	Southern Precision Steel Co. (Precision Drawn Steel Co.)		CA

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
MISSOURI				
Kansas City	Jackson	Armco Steel Corp.	Elec.	CA
St. Louis	St. Louis	Missouri Rolling Mill Corp.		C
NEBRASKA				
Cozad	Dawson	Monroe Auto Equipment Co.		C
Valley	Douglas	Valmont Industries, Inc.		C
NEW JERSEY				
Camden	Camden	Precision Drawn Steel Co.		C
Clifton	Passaic	National-Standard Co.		C
Harrison	Hudson	Crucible Steel Corp.		CA
Metuchen	Middlesex	Berger Industries		C
New Brunswick	"	Carpenter Steel Co.		C
New Market	"	Union Steel Corp. (Sharon Steel Corp.)		CAS
Newark	Essex	Wilbur B. Driver Co.		AS
"	"	Igoe Brothers, Inc.		C
"	"	Screw and Bolt Corp. of America Wyckoff Steel Div.		CA
Roebling	Burlington	CF&I Steel Corp.	Elec.	C
Trenton	Mercer	CF&I Steel Corp.		C
"	"	United States Steel Corp. Wire Products Oprs.		C
Union	Union	Carpenter Steel Co.		C
"	"	Union Steel Corp. (Sharon Steel Corp.)		CAS
NEW YORK				
Brooklyn	Kings	Republic Steel Corp.		CA
Buffalo	Erie	Bliss & Laughlin Steel Co.		CA
"	"	Donner-Hanna Coke Corp.	Coke	
"	"	Gibraltar Steel Corp.		C

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
NEW YORK (Cont'd.)				
Buffalo	Erie	Madison Wire Co., Inc.		C
"	"	National Steel Corp.		
		Hanna Furnace Corp.	B/F	
"	"	Republic Steel Corp.	B/F-OH	CA
Cortland	Cortland	Wickwire Brothers, Inc.	Elec.	C
Dunkirk	Chautauqua	Allegheny Ludlum Steel Corp.	Elec.	CAS
"	"	Roblin Steel Corp.	Elec.	CA
Lackawanna	Erie	Bethlehem Steel Corp.	Coke-B/F-OH-Bop	CA
Lockport	Niagara	Wallace Murray Corp.		
		Simonds Steel Div.	Elec.	CAS
New Hartford	Oneida	Allegheny Ludlum Steel Corp.		
		Special Metals Corp.	Elec.	C
New York	New York	Washburn Wire Co.		C
No. Tonawanda	Niagara	Roblin Steel Corp.		CA
" "	"	Tonawanda Iron Div.		
		(Am. Rad. & Std. Corp.)	B/F	
Rome	Oneida	Rome Manufacturing Co.		CAS
"	"	Rome Strip Steel Co., Inc.		CA
Syracuse	Onondaga	Crucible Steel Corp.	Elec.	CAS
Tonawanda	Erie	Lake Erie Rolling Mill, Inc.		CA
Troy	Rensselaer	Poor & Co.		C
"	"	Republic Steel Corp.	B/F	
Watervliet	Albany	Allegheny Ludlum Steel Corp.	Elec.	AS
NORTH CAROLINA				
Monroe	Union	Vasco Metals Corp.		
		Allvac	Elec.	CA
Croft	Mecklenburg	Florida Steel Corp.	Elec.	C

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APPENDIX

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
OHIO				
Akron	Summit	National-Standard Co.		C
"	"	Pittsburgh Steel Co. Johnson Steel & Wire Co., Inc.		C
Alliance	Stark	Babcock & Wilcox Co.		C
Campbell	Mahoning	Youngstown Sheet and Tube Co.	Coke-B/F-OH	CA
Canton	Stark	Poor & Co.		CA
"	"	Republic Steel Corp.	B/F-OH-Elec.	CAS
"	"	Timken Roller Bearing Co.	Elec.	CAS
"	"	United States Steel Corp. Sheet & Tin Products Oprs.		C
Cincinnati	Hamilton	American Compressed Steel Corp.	Elec.	C
Cleveland	Cuyahoga	Angell Nail & Chaplet Co.		C
"	"	Cuyahoga Steel & Wire Co. (Div. Hoover Ball & Bearing Co.)		CA
"	"	Jones & Laughlin Steel Corp.	B/F-Bop-Elec.	CA
"	"	Republic Steel Corp.	Coke-B/F-OH-Bop	CA
"	"	Solar Steel Corp.		CA
"	"	United States Steel Corp. Wire Products Oprs.		CA
		Tubular Products Oprs.	B/F	
"	"	United Tube Corp. of Ohio		C
Coshocton	Coshocton	Universal-Cyclops Specialty Steel Div. (Cyclops Corp.)		S
Dover	Tuscarawas	Greer Steel Co.		CA
"	"	Cyclops Corp. Empire-Reeves Steel Div.	OH-Elec.	CAS
"	Lorain	Republic Steel Corp.		C
	"	Western Cold Drawn Steel (Standard Screw Co.)		CA
Fostoria	Seneca	Seneca Wire & Manufacturing Co.		C

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
OHIO (Cont'd.)				
Hubbard	Trumbull	Valley Mould & Iron Corp.	B/F	
Jackson	Jackson	Jackson Iron & Steel Co.	B/F	
Lorain	Lorain	United States Steel Corp. Tubular Products Oprs.	Coke-B/F-OH-Bess	CA
Louisville	Stark	Jones & Laughlin Steel Corp. Stainless and Strip Div.		S
Mansfield	Richland	Cyclops Corp. Empire-Reeves Steel Div.	OH-Elec.	CAS
Marion	Marion	Pollak Steel Co.		C
Martins Ferry	Belmont	Wheeling Steel Corp.		C
Massillon	Stark	Republic Steel Corp.	Coke-B/F	
Medina	Medina	Bliss & Laughlin Steel Co.		CA
Middletown	Butler	Armco Steel Corp.	Coke-B/F-OH	C
Orwell	Ashtabula	Welded Tubes, Inc.		C
Piqua	Miami	Miami Industries Div. (MSL Industries, Inc.)		C
Portsmouth	Scioto	Detroit Steel Corp.	Coke-B/F-OH	C
Shelby	Richland	Copperweld Steel Co. Ohio Seamless Tube Div.		CA
"	"	Standard Tube Co. (Michigan Seamless Tube Co.)		C
Steubenville	Jefferson	National Steel Corp. Weirton Steel Div.		C
"	"	Wheeling Steel Corp.	Coke-B/F-OH-Bop	CA
Toledo	Lucas	AP Parts Corp.		C
"	"	Baron Drawn Steel Corp.		CA
"	"	Interlake Steel Corp.	Coke-B/F	
"	"	Kaiser Jeep Corp.		C
"	"	Toledo Steel Tube Co.		C
Warren	Trumbull	Copperweld Steel Co.	Elec.	CAS
"	"	Pittsburgh Steel Co. Thomas Strip Div.		C

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
OHIO (Cont'd.)				
Warren	Trumbull	Republic Steel Corp.	Coke-B/F-Bop-Elec.	CA
"	"	Sharon Steel Corp.		
"	"	Brainard Steel Strapping Div.		C
		Van Huffel Tube Corp. (Youngstown Sheet & Tube Co.)		CAS
Wooster	Wayne	Timken Roller Bearing Co.		CAS
Yorkville	Jefferson	Wheeling Steel Corp.		C
Youngstown	Mahoning	Jones & Laughlin Steel Corp. Stainless & Strip Div.		CAS
"	"	Fitzsimons Steel Co., Inc.		CA
"	"	Republic Steel Corp.	Coke-B/F-OH	CA
"	"	United States Steel Corp. Tubular Products Oprs.	B/F-OH	CA
"	"	Youngstown Sheet and Tube Co.	Coke-B/F-OH	CA
Zanesville	Muskingum	Armco Steel Corp.		A
New Miami	Butler	Armco Steel Corp.	Coke-B/F	
OKLAHOMA				
Oklahoma City	Oklahoma	Hoster Investment Co.		C
Sand Springs	Tulsa	Armco Steel Corp.	Elec.	C
OREGON				
Portland	Multnomah	Oregon Steel Mills	Elec.	C
PENNSYLVANIA				
Aliquippa	Beaver	Jones & Laughlin Steel Corp.	Coke-B/F-OH-Bess-Bop	CAS
Allenport	Washington	Pittsburgh Steel Co.		CAS
Ambridge	Beaver	A. M. Byers Co.		
"	"	Armco Steel Corp.		CA

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
PENNSYLVANIA (Cont'd.)				
Ambridge	Beaver	Screw & Bolt Corp. Wyckoff Steel Div.		C
Avis	Clinton	Jersey Shore Steel Co.		C
Beaver Falls	Beaver	Babcock & Wilcox Co.	Elec.	CAS
"	"	Moltrup Steel Products Co.		CA
"	"	Republic Steel Corp.		CA
Bethlehem	Northampton	Bethlehem Steel Corp.	Coke-B/F-OH-Elec.	CAS
Brackenridge	Allegheny	Allegheny Ludlum Steel Corp.	Bop-Elec.	CAS
Braddock	"	United States Steel Corp. Heavy Products Oprs.	B/F-OH	
Braeburn	Westmoreland	Braeburn Alloy Steel Corp.	Elec.	CA
Bridgeville	Allegheny	Universal-Cyclops Specialty Steel Div. (Cyclops Corp.)	Elec.	CAS
Burham	Mifflin	Baldwin-Lima-Hamilton Corp. Standard Steel Works Div.		CAS
Butler	Butler	Armco Steel Corp.		CAS
Carnegie	Allegheny	Columbia Steel & Shafting Co. (Columbia-Summerill)		CAS
"	"	Union Electric Steel Corp.	Elec.	A
Catasauqua	Lehigh	Phoenix Manufacturing Co.		C
Clairton	Allegheny	United States Steel Corp. Heavy Products Oprs.	Coke-B/F	CA
Coatesville	Chester	Lukens Steel Co.	OH-Elec.	CA
Corry	Erie	McInnes Steel Co.		CAS
Dravosburgh	Allegheny	United States Steel Corp. Sheet & Tin Products Oprs.		CAS
Duquesne	"	Heavy Products Oprs.	B/F-Bop-Elec.	CAS
Ellwood	Lawrence	United States Steel Corp. Tubular Products Oprs.		CA
Erie	Erie	Erie Forge & Steel Corp.	Elec.	CA
"	"	Interlake Steel Corp.	Coke-B/F	

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
PENNSYLVANIA (Cont'd.)				
Fairless Hills	Bucks	United States Steel Corp.		
		Sheet & Tin Products Oprs.	Coke-B/F-OH	CAS
"	"	Tubular Products Oprs.		C
Farrell	Mercer	Sharon Steel Corp.	B/F-OH-Bop-Elec.	CAS
Franklin	Venango	Borg-Warner Corp.		
		Franklin Steel Div.		C
Glassport	Allegheny	Copperweld Steel Co.		CA
Greenville	Mercer	Damascus Tube Co.		S
Harrisburg	Dauphin	Harsco Corp.		
		Harrisburg Steel Co.	OH	CA
Hometown	Schuylkill	Bundy Corp.		C
Houston	Washington	Washington Steel Corp.	Elec.	
Irvine	Warren	National Forge Co.	Elec.	CAS
Ivy Rock	Montgomery	Alan Wood Steel Co.	OH	CA
Johnstown	Cambria	Bethlehem Steel Corp.	Coke-B/F-OH	CA
"	"	United States Steel Corp.		
		Heavy Products Oprs.	Elec.	CAS
Latrobe	Westmoreland	Alco Products, Inc.	OH	CA
"	"	Latrobe Steel Co.	Elec.	CAS
"	"	Vanadium-Alloys Steel Co.	Elec.	CA
"	"	Vanadium Plant		CA
Lebanon	Lebanon	Bethlehem Steel Corp.		CA
McKeesport	Allegheny	United States Steel Corp.		
		Tubular Products Oprs.		
		(Christy Park Wks.)		
		(National Wks.)	B/F-OH-Bess	CA
Midland	Beaver	United States Steel Corp.		
		Heavy Products Oprs.		C
		Crucible Steel Corp.	Coke-B/F-OH-Elec.	CAS
Milton	Northumberland	Ceco Corp.		
		Milton Mfg. Co.	Elec.	CA

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
PENNSYLVANIA (Cont'd.)				
Monaca	Beaver	Pittsburgh Tube Co.		C
"	"	Superior Drawn Steel Co.		C
"	"	Vanadium-Alloys Steel Co.		
		Colonial Steel Plant	Elec.	CAS
		Pittsburgh Plant		C
Monessen	Westmoreland	American Chain & Cable Co., Inc.		
		Page Steel & Wire Div.		CAS
"	"	Pittsburgh Steel Co.	Coke-B/F-OH-Bop	CA
Muncy	Lycoming	Jones & Laughlin Steel Corp.		C
Munhall	Allegheny	United States Steel Corp.		
		Heavy Products Oprs.	OH	CA
Neville Island	"	Shenango Furnace Co.	Coke/BF	
New Brighton	Beaver	Townsend Co.		CA
New Castle	Lawrence	Blair Strip Steel Co.		C
" "	"	Mesta Machine Co.	OH	C
New Kensington	Westmoreland	American Shim Steel Co.		C
Norristown	Montgomery	Superior Tube Co.		CAS
Oakmont	Allegheny	Edgewater Corp.	Elec.	CA
Oil City	Venango	Jones & Laughlin Steel Corp.		C
Philadelphia	Philadelphia	Philadelphia Steel & Wire Corp.		C
"	"	Heppenstall Co.		
		Midvale-Heppenstall Co.	Elec.	CAS
Phoenixville	Chester	Phoenix Steel Corp.	OH	CA
Pittsburgh	Allegheny	Cyclops Corp.		
		Universal-Cyclops Specialty Stl. Div.		CAS
"	"	Crucible Steel Corp.		C
"	"	Heppenstall Co.	OH	CA

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TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
PENNSYLVANIA (Cont'd.)				
Pittsburgh	Allegheny	Jones & Laughlin Steel Corp.	Coke-B/F-OH-Elec.	CA
Rahns	Montgomery	Techalloy Co., Inc.		C
Rankin	Allegheny	United States Steel Corp. Heavy Products Oprs.	B/F	
Reading	Berks	Carpenter Steel Co.	Elec.	CAS
Scottdale	Westmoreland	Columbia Steel & Shafting Co. (Columbia-Summerill)		S
Sharon	Mercer	Sawhill Tubular Div. (Cyclops Corp.)		C
"	"	Sharon Tube Co.		C
Sharpsville	Allegheny	Shenango Furnace Co.	B/F	
Sheridan	Lebanon	E. J. Lavino & Co.	B/F	
Sinking Springs	Berks	Hofmann Industries, Inc.		C
South Avis	Clinton	Jersey Shore Steel Co.		C
Spring City	Chester	Keystone Drawn Steel Co. (La Salle Steel Co.)		CA
Steelton	Dauphin	Bethlehem Steel Corp.	OH-Elec.	CA
Swedeland	Montgomery	Alan Wood Steel Co.	Coke-B/F	
Templeton	Armstrong	Carpenter Coal & Coke Co.		
Titusville	Crawford	Cyclops Corp. Universal-Cyclops Specialty Stl. Div.		AS
Uniontown	Fayette	Cavert Wire Co., Inc.		C
Vandergrift	Westmoreland	United States Steel Corp. Sheet and Tin Products Oprs.		CAS
Washington	Washington	Jessop Steel Co.	Elec.	CAS
"	"	Washington Steel Corp.		S
West Homestead	Allegheny	Mesta Machine Co.	OH-Elec.	CA

(continued)

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
PENNSYLVANIA (Cont'd)				
West Leechburg	Westmoreland	Allegheny Ludlum Steel Corp.		CAS
Wheatland	Mercer	Sawhill Tubular Div. (Cyclops Corp.)		C
"	"	Wheatland Tube Co.		C
Williamsport	Lycoming	Bethlehem Steel Corp.		C
RHODE ISLAND				
Pawtucket	Providence	Newman-Crosby Steel Co.		CAS
Phillipsdale	"	Washburn Wire Co.	OH	CA
SOUTH CAROLINA				
Cayce	Lexington	Owen Electric Steel Co. of S.C.	Elec.	C
TENNESSEE				
Chattanooga	Hamilton	Woodward Corp.	Coke	
Counce	Hardin	Cal-Metal Corp.		C
Knoxville	Knox	Knoxville Iron Co.	Elec.	CA
Lyles-Wrigley	Hickman	Merritt-Chapman & Scott Corp. Tenn. Products & Chemical Corp.	B/F	
Memphis	Shelby	Poor and Co.		CA
Murfreesboro	Rutherford	Samsonite Corp.		C
Harriman	Roane	Tennessee Forging Steel Corp.	Elec.	C
TEXAS				
Fort Worth	Tarrant	Texas Steel Co.	Elec.	C
Galveston	Galveston	Kane Boiler Works, Inc.		C
Houston	Harris	Armco Steel Corp.	Coke-B/F-OH-Elec.	CAS
"	"	Bliss & Laughlin Steel Co.		CA
"	"	Cameron Iron Works, Inc.	Elec.	CA
"	"	Detroit Steel Corp. Tex Tube Div.		C

(continued)

APPENDIX

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
TEXAS (Cont'd.)				
Houston	Harris	A. O. Smith Corp. of Texas		C
"	"	Southwestern Pipe, Inc.		C
Lone Star	Morris	Lone Star Steel Co.	Coke-B/F-OH	C
Longview	Gregg	R. G. Le Tourneau, Inc.	Elec.	CA
Pampa	Gray	Cabot Corp.	Elec.	A
Rosenberg	Fort Bend	Michigan Seamless Tube Co. Gulf States Tube Corp.		CAS
Seguin	Guadalupe	Structural Metals, Inc.	Elec.	C
Sherman	Grayson	Mid-States Steel & Wire Co. (Keystone Consl. Industries)		C
Vinton	El Paso	Border Steel Rolling Mills	Elec.	CA
UTAH				
Geneva	Utah	United States Steel Corp. Sheet and Tin Products Oprs.	Coke-B/F-OH	CA
VIRGINIA				
Chesapeake	Northampton	Intercoastal Steel Corp.	Elec.	CA
Harrisonburg	Rockingham	Walker Manufacturing Co.		CAS
Lynchburg	Campbell	E. J. Lavino & Co.	B/F	
Newport News	"	Newport News Shipbuilding & Drydock Co.	Elec.	CAS
Richmond	Chesterfield	Tredegar Co.		C
Roanoke	Roanoke	Roanoke Electric Steel Corp.	Elec.	C
WASHINGTON				
Seattle	King	Bethlehem Steel Corp.	Elec.	CA
		Bliss & Laughlin Steel Co.		C
"	"	Davis Wire Corp.		C
"	"	Jorgensen Co., E. M.	Elec.	CAS

(continued)

APPENDIX

TABLE 4

IRON AND STEEL PRODUCING AND FINISHING WORKS OF THE UNITED STATES, 1967[63] (Continued)

State & City	County	Company	Major Furnaces	Grades of Steel*
WASHINGTON (Cont'd.)				
Seattle	King	Northwest Steel Rolling Mills, Inc.	Elec.	C
WEST VIRGINIA				
Fairmont	Marion	Sharon Steel Corp.	Coke	
Follansbee	Brooke	Wheeling Steel Corp.		
Huntington	Cabell	H. K. Porter Co., Inc. Connors Steel Div.		C
Weirton	Hancock	National Steel Corp. Weirton Steel Div.	Elec.	CA
Wheeling	Ohio	Wheeling Steel Corp.	Coke-B/F-OH-Bop	CA CA
WISCONSIN				
Cedarburg	Ozaukee	Cedarburg Wire, Wire Nail & Screw Co.		C
East Troy	Walworth	Crucible Steel Corp. Trent Tube Div.		
Green Bay	Brown	Fort Howard Steel & Wire Div.		S
Kenosha	Kenosha	Macwhyte Co.		C
Milwaukee	Milwaukee	Babcock & Wilcox Co.		CS
"	"	A. O. Smith Corp.		CAS
Racine	Racine	Walker Mfg. Co.		CA CAS

*Grades of Steel - C - Carbon, A - Alloy, S - Stainless

B/F - Blast Furnace.
OH - Open Hearth.
Bop - Basic Oxygen Process.
Elec - Electric Furnace.

TABLE 5

PRODUCTION OF PIG IRON AND FERROALLOYS BY STATES, 1967, 1960[11]

State	Thousands of Short Tons 1967	Thousands of Short Tons 1960
PIG IRON		
New York	6,172	4,205
Pennsylvania	20,542	16,533
Maryland, West Virginia, Kentucky, Tennessee, Texas	10,824	7,987
Alabama	4,290	3,541
Ohio	14,485	11,788
Indiana	12,167	8,404
Illinois	6,309	5,307
Michigan, Minnesota	7,439	4,981
Colorado, Utah, California	4,756	3,735
Total	86,756	66,481
FERROALLOYS		
New York	109	153
Pennsylvania	468	510
Virginia, West Virginia, South Carolina, Tennessee	559	345
Ohio	734	658
Other States	618	419
Total	2,488	2,085
Grand Total	89,472	68,566

TABLE 6

RAW STEEL PRODUCTION[11]

	Thousands of Short Tons				
Year	Open-Hearth	Bessemer	Basic Oxygen Process	Electric	Total
1967	70,690	*	41,434	15,089	127,213
1966	85,025	278	33,928	15,870	134,161
1965	94,193	586	22,879	13,804	131,462
1964	98,098	858	15,442	12,678	127,076
1963	88,834	963	8,544	10,920	109,261
1962	82,957	805	5,553	9,013	98,328
1961	84,502	881	3,967	8,664	98,014
1960	86,368	1,189	3,346	8,379	99,282
1959	81,669	1,380	1,864	8,533	93,446
1958	75,880	1,396	1,323	6,656	85,255
1957	101,658	2,475	611	7,971	112,715
1956	102,840	3,228	506	8,641	115,216
1955	105,359	3,320	307	8,050	117,036
1954	80,328	2,548		5,436	88,312
1953	100,474	3,856		7,280	111,610

*Included in open-hearth figures.

TABLE 7

IRON EMISSIONS FROM METALLURGICAL PROCESSES[114]

Furnace	Iron (Fe_2O_3) in Particulate (Percent)	Dust Emission Rate (pounds dust/ton ore) No Control	Dust Emission Rate (pounds dust/ton ore) Control	Iron (Fe_2O_3) Emission Rate (pounds/ton ore) No Control	Iron (Fe_2O_3) Emission Rate (pounds/ton ore) Control
Ferromanganese blast furnace	0.3-0.5	360	60	1.1-1.8	0.18-0.30
Open-hearth furnace	50-90	9.3	1.7	4.6-8.3	0.85-1.5
Electric-arc steel furnace	40-50	11	1.2	4.4-5.5	0.48-0.60
Basic oxygen furnace	90	20-40	0.2-0.4	18-36	0.18-0.36
Blast furnace	30	100	0.4-0.2	30	0.12-0.06
Sintering plant	50	20	2-4	10	1-2

TABLE 8

IRON EMISSIONS FROM COAL-FIRED POWER PLANTS[36]

Type of Boiler Firing	Coal Rate ton/hr	Ash in Coal (as fired) %	Flue Gas Volume scfm x 10^3		Iron Emissions					
					ug/m^3		kg/min		kg/ton	
			B	A	B	A	B	A	B	A
Vertical	65.6	20.2	397.4	409.9	110,000	3,900	1.2	.045	1.1	.041
Corner	56.1	14.9	362.9	351.0	433,000	23,000	4.4	.23	4.7	.25
Front-wall	52.2	10.3	329.0	328.0	110,000	13,000	1.0	.12	1.1	.14
Spreader-stoker	9.2	8.4	53.9	59.6	250,000	87,000	.38	.15	2.4	.98
Cyclone	64.4	7.7	553.6	500.8	310,000	87,000	4.9	1.2	4.6	1.1
Horizontally opposed	9.6	8.2	62.2	62.2	1,550,000	166,000	2.7	.29	17.	1.8

A: After fly-ash collection.

B: Before fly-ash collection.

TABLE 9. CONCENTRATION OF IRON IN THE AIR[1,3,5,6]
(µg/m³)

Location	1954-59		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
Alabama												
Birmingham											11.0	2.3
Arizona												
Phoenix			41.0	13.5			8.1	2.9			16.0	2.5
California												
Los Angeles	11.4	6.2	8.8	3.2	8.4	2.6	12.0	4.7	4.3	1.3		
San Francisco	0.8	0.2					2.8	0.7	3.7	0.6		
Colorado												
Denver	5.3	1.8					7.2	2.6	5.5	1.9	2.4	1.2
District of Columbia												
Washington	10.1	3.9					2.8	1.4	3.1	1.1	2.6	1.0
Georgia												
Atlanta	7.3	2.6							3.0	1.2		
Idaho												
Boise			2.2	1.2			2.5	1.1			1.3	0.7
Illinois												
Chicago	15.5	4.0			8.7	4.0			8.0	1.8	3.3	1.6
Cicero							9.6	2.8				
East St. Louis	10.0	2.8							13.0	3.0		
Indiana												
East Chicago	30.0	3.6									22.0	5.5
Indianapolis					5.8	2.8	2.8	1.4				
Iowa												
Des Moines			7.9	2.7			6.0	1.4			2.0	0.9
Louisiana												
New Orleans	4.0	0.6					2.6	0.7	2.5	0.7		
Maryland												
Baltimore	13.0	3.0			5.4	2.9	4.8	1.6			16.0	2.2
Massachusetts												
Boston	1.7	0.5									1.7	0.9
Michigan												
Detroit							3.5	1.3	6.9	1.5	8.2	1.8
Missouri												
St. Louis	2.9	1.4					8.6	2.2	3.0	1.1	3.0	1.1
Montana												
Helena											2.1	0.5

(continued)

TABLE 9. CONCENTRATION OF IRON IN THE AIR[1,3,5,6] (Continued)
($\mu g/m^3$)

Location	1954-59		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
Nevada												
Las Vegas							18.0	2.8	5.1	1.4	4.4	1.5
New Jersey												
Newark					17.0	2.2	4.1	1.8			3.1	1.3
Nebraska												
Omaha	29.0	4.8					3.7	1.5				
New York												
Buffalo							10.0	1.8				
New York	10.7	3.3			14.0	3.3	6.2	2.8	4.1	1.5	1.9	0.9
North Carolina												
Charlotte											8.6	1.0
Ohio												
Cincinnati	12.7	4.5	26.0	5.4	30.0	5.0	23.0	4.7	13.0	1.9	13.0	2.5
Cleveland							9.8	2.8	5.2	2.4	4.0	1.5
Pennsylvania												
Allentown					6.9	2.6						
Philadelphia	15.7	1.2	11.0	4.5	8.6	3.7	6.6	3.4	4.3	1.8	3.2	1.7
Pittsburgh	16.0	3.5					11.0	3.4	19.0	3.0	12.0	2.8
Scranton					15.0	3.9						
Tennessee												
Chattanooga	3.3	0.9			9.6	4.2					3.6	1.6
Texas												
El Paso							3.9	1.9			4.2	1.3
Washington												
Seattle	10.0	3.8					2.3	1.0	1.8	0.7		
Tacoma							1.2	0.5			1.3	0.4
West Virginia												
Charleston	8.1	2.8			33.0	8.3					5.3	1.7
Wisconsin												
Milwaukee	14.0	3.2									7.7	1.9
Wyoming												
Cheyenne											0.8	0.3
United States											22.0*	1.58*

*Average 1962-1964.

TABLE 10. EMISSIONS FROM STEEL MILLS[82,78]

Operation	Before Control		Emission with Control				Approx. Value of Gases Handled
	Stack Loading (g/m^3)[a]	lb/ton of Product[a]	Control Used[c]	Stack Loading (g/m^3)	lb/ton of Product	Approx. Effi-ciency (percent)	
Blast furnace	16-22.8	200	Preliminary cleaner (settling chamber or dry cyclone)[b]	7-14		60	87,000 scfm for a 1,000-ton/day furnace
			Primary cleaner (wet scrubber)[b]	0.11-0.7-1.6	5.4	90	
			Secondary cleaner (E.S.P. or V.S.)[b]	0.009-0.018	0.1-1.4	90	
Sintering machine	1.1-6.9	5-20-100	Dry cyclone	0.45-1.3	2.0	90	120,000-160,000 scfm for a 1,000-ton/day machine
			E.S.P. (in series with dry cyclone)	0.02-0.11	1.0	95	
Sinter machine discharge - crusher, screener, and cooler	13	22	Dry cyclone	0.9	1.5	93	17,500 scfm for a 1,000-ton/day machine
Open-hearth (not oxygen-lanced)	0.22-0.9-4.5	1.5-7.5-20.0	E.S.P.	0.02-0.11	0.15	98	35,000 scfm for a 175-ton furnace
			V.S.	0.02-0.14	0.15-1.1	85-98	
			Baghouse	0.02	0.07	99	

(continued)

TABLE 10. EMISSIONS FROM STEEL MILLS[82,78] (Continued)

Operation	Before Control		Emission with Control				Approx. Value of Gases Handled
	Stack Loading (g/m^3)[a]	lb/ton of Product[a]	Control Used[c]	Stack Loading (g/m^3)	lb/ton of Product	Approx. Efficiency (percent)	
Open-hearth (with oxygen lance)	0.2-1.4-5.7	9.3	E.S.P.	0.02-0.013	0.2	98	35,000 scfm for a 175-ton furnace
			V.S.	0.02-0.14	0.2-1.4	85-98	
Electric-arc furnace	0.22-0.91-13	4.5-10.6-37.8	High efficiency scrubber	0.02	0.2	Up to 98	Highly variable depending on type of hood. May be about 30,000 scfm for a 50-ton furnace
			E.S.P.	0.02-0.09	0.3-0.8	92-97	
			Baghouse	0.02	0.1-0.2	98-99	
Bessemer converter	1.8->23	15-17-44	No practical method of control				
Basic oxygen furnace	11-18	20-40-60	V.S.	0.06-0.27	0.4	99	Varies with amount of oxygen blown. 20 to 25 scfm per cfm of oxygen blown
			E.S.P.	0.11	0.4	99	
Scarfing machine	0.4-1.8	3 lb/ton of steel processed	Settling chamber	No data	No data	No data	85,000 scfm for a 45-inch, 4-side machine

[a] When three values are given, such as 5-20-100, the center value is the approximate average and values at either end are the lowest and highest values reported. All data are highly variable depending on nature of a specific piece of equipment, materials being processed, and operating procedure.

[b] Used in series. Data on that basis.

[c] V.S.: venturi scrubber.
E.S.P.: electrostatic precipitator.

APPENDIX

TABLE 11

PAPERS RELATING TO CONTROL METHODS IN THE IRON AND STEEL INDUSTRY

Process	Reference
Basic oxygen furnace	20, 30, 37, 52, 58, 59, 70, 80, 86, 88-90, 94, 97, 118, 137, 138, 146, 147
Electric furnace	16-18, 24, 27, 37, 38, 40, 48, 60, 61, 65, 66, 92, 115, 149
Open-Hearth furnace	12, 19, 26, 37, 70, 113, 116, 117, 121, 134, 150, 151
Blast furnace	37, 45, 53, 79, 104, 148
Cupola	13, 37, 50, 127, 133, 139, 147
General	23, 37, 41, 42, 45, 47, 56, 57, 62, 74, 81, 85, 87, 93, 99, 102, 103, 118, 121, 124, 125, 130, 141, 145

APPENDIX

TABLE 12

EXPENDITURES FOR POLLUTION CONTROL BY THE STEEL INDUSTRY

	Millions of Dollars		
Year	Air	Water	Total
1968*	102	120	222
1967	39.4	54.7	94.1
1966	37.7	18.8	56.5
1951-67			~600

*Includes committed funds for control equipment that may not have been completed and placed in operation in 1968.

TABLE 13

NUMBER OF BLAST FURNACES ON JANUARY 1, 1968

PRODUCING PIG IRON AND FERROALLOYS[83]

State	1968		1967		1966		1965		1964	
	In Blast	Total	In Blast	Total	In Blast	Total	In Blast	Total	In Blast	Total
					PIG IRON					
Alabama	9	17	10	17	8	18	15	18	10	20
California	4	4	4	4	4	4	4	4	3	4
Colorado	4	4	4	4	4	4	3	4	3	4
Illinois	14	18	12	19	12	22	16	22	7	22
Indiana	22	24	20	23	21	23	21	23	21	23
Kentucky	2	3	2	3	2	3	2	3	2	3
Maryland	10	10	7	10	7	10	10	10	6	10
Michigan	9	9	9	9	9	9	9	9	9	9
Minnesota	1	2	2	2	1	2	2	2	1	2
New York	12	15	12	15	11	15	12	15	9	16
Ohio	33	47	29	48	26	49	36	49	27	49
Pennsylvania	39	58	38	59	34	56	45	58	34	60
Tennessee	0	3	0	3	0	3	0	3	1	3
Utah	3	3	3	3	2	5	3	5	2	5
West Virginia	4	4	4	4	3	4	4	4	3	4
					FERROALLOYS					
All States	5	7	6	7	5	7	7	8	5	8
Total	173	230	164	232	151	236	191	239	147	244

APPENDIX

TABLE 14

U.S. CAPACITY FOR STEEL PRODUCTION, JAN. 1, 1960[84]

State	Electric Furnace		Blast Furnace		Open-Hearth Furnace		Basic Oxygen Steel Furnace	
	No. of Plants/ Furnaces	Annual Capacity (net tons)	No. of Plants/ Furnaces	Annual Capacity (net tons)	No. of Plants/ Furnaces	Annual Capacity (net tons)	No. of Plants/ Furnaces	Annual Capacity (net tons)
Ohio	8/36	3,078,600	22/52	18,734,500	17/169	22,688,280		
Pennsylvania	31/105	2,888,780	23/76	26,381,750	30/283	34,944,350	1/2	880,000
Illinois	8/28	2,400,400	6/22	7,955,200	6/62	9,842,000	1/2	452,000
Michigan	4/20	1,178,600	3/9	5,290,250	2/27	5,420,000	1/5	1,385,400
Texas	5/12	699,080	2/2	925,000	2/13	1,825,000		
Alabama	4/8	670,020	7/22	5,817,440	3/31	4,786,000		
California	3/8	628,000	1/4	1,997,800	6/30	2,727,500	1/3	1,440,000
Kentucky	2/5	466,190	1/3	1,058,000	2/15	1,363,000		
Missouri	1/2	420,000			1/4	420,000		
Washington	3/6	401,000						
Georgia	1/2	325,000						
New York	6/28	225,010	6/17	5,947,000	3/47	7,195,000		
Maryland	2/11	180,960	1/10	5,480,000	1/35	7,864,000		
Oregon	1/3	150,000						
Oklahoma	1/1	140,000						
West Virginia	1/1	117,000	2/5	2,646,000	1/14	3,300,000		
Indiana	2/7	101,500	3/23	10,324,350	4/120	18,339,000		
Connecticut	1/2	84,000						
Arizona	1/2	60,000						
Florida	1/1	51,000						
Mississippi	1/1	45,000						
Virginia	2/4	40,000	1/2	128,000				
Tennessee	1/2	38,000	2/3	217,740				
New Jersey	1/6	7,800			1/9	235,000		
Colorado			1/4	922,400	1/17	1,800,000		
Minnesota			2/3	696,000	1/9	973,000		
Massachusetts			1/1	195,000				
Utah			2/5	1,804,200	1/10	2,300,000		
Rhode Island					1/4	93,000		
Delaware					1/7	506,500		
Total	91/301	14,395,940	86/263	96,520,630*	84/906	126,621,630	4/12	4,157,400

*Includes 877,500 tons ferroalloys capacity.

APPENDIX

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS[82]

Compound	Properties	Toxicity	Uses
Dextran iron complex			Med. use: in iron-deficiency anemia when parenteral (im) administration is indicated. Vet. use: for iron-deficiency anemia, particularly in baby-pig anemia
Ferric acetate, basic $FE(OH)(CH_3COO)_2$			In textile industry as a mordant in dyeing and printing, and for the weighting of silk and felt; as wood preservative; in leather dyes; as medicament
Ferric bromide $FeBr_3$	Decomposes	Irritant. Liberates irritating fumes of bromine	As catalyst for organic reactions, particularly in bromination of aromatic compounds
Ferric chloride $FeCl_3$	Melts and volatilizes about 300°C bp 316°C	Anhydrous form is irritant, astringent	In photoengraving, photography, manufacture of other Fe salts, pigments, ink; as a catalyst in organic reactions; purifying factory effluents and deodorizing sewage; chlorination of Ag and Cu ores; as mordant in dyeing and printing textiles; oxidizing agent in dye manufacture. Med. use: hexahydrate topically as astringent, styptic; in test for phenylketonuria. Vet. use: styptic, astringent in skin diseases, stomatitis pharyngitis. Rarely used internally

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Ferric chromate VI $Fe_2(CrO_4)_3$			As pigment for ceramics, glass, and enamels
Ferric ferrocyanide $Fe_4(Fe(CN)_6)_3$			As pigment in printing inks, paints, alkyd resin enamels, linoleum, leather, cloth, carbon papers, typewriter ribbons, rubbers, plastics, artists' colors; in removal of H_2S from gases
Ferric fluoride FeF_3	Sublimes at 1000°C		As catalyst in organic reactions
Ferric formate $Fe(HCOO)_3$			For preservation of silage
Ferrichromes $C_{27}H_{42}FeN_9O_{12}$	Shrink and blacken at 240-242°C without melting		As growth-promoting agents (iron chelates produced by rust fungus)
Ferric hydroxide $Fe(OH)_3$		Practically nontoxic	In purifying water; as absorbent in chemical processing; as pigment; as catalyst
Ferric nitrate $Fe(NO_3)_3$	mp 47°C		As mordant in dyeing, weighting silks, tanning; as reagent in analytical chemistry; as corrosion inhibitor

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Ferric oxide hematite Fe_2O_3	mp 1565°C	Hematite dust causes a benign pneumoconiosis	As pigment for rubber, paints, paper, linoleum, ceramics, glass; in paint for ironwork, ship hulls; as polishing agent for glass, precious metals, diamonds; in electrical resistors; as semiconductor in magnetic tapes, magnets; as catalyst
Ferric phosphate $FePO_4$			As food and feed supplement, particularly in bread enrichment; as fertilizer
Ferric subsulfate solution $Fe_4(OH)_2(SO_4)_5$		Practically nontoxic. A mild local irritant. Large doses orally can cause diarrhea	As mordant in dyeing textiles. Med. use: styptic for local use on skin. Vet. use: locally as styptic. Diluted for oral use in gastrointestinal tract hemorrhages
Ferric sulfate $Fe_2(SO_4)_3$	Decomposes at 480°C		In preparation of iron alums, other iron salts and pigments; as coagulant in water purification and sewage treatment; in etching aluminum; in pickling stainless steel and copper; as mordant in textile dyeing and calico printing; in soil conditioners; as polymerization catalyst
Ferric thiocyanate $Fe(SCN)_3$			As analytical reagent

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Ferrite Fe_2O_3		The dust can cause pulmonary irritation	For radio and television coil cores, slug tuners, loop-stick antennas
Ferrocene $C_{10}H_{10}Fe$	mp 173-174°C	No specific data. Animal feeding experiments show almost complete absence of toxicity	As antiknock additive for gasoline, catalyst
Ferrosoferric oxide magnetite Fe_3O_4	mp 1538°C		As pigment in paints, linoleum, ceramic glazes; in coloring glass; as polishing compound; in textile industry; in cathodes; as catalyst
Ferrous bromide $FeBr_2$	mp 684°C		As polymerization catalyst. Med. use: formerly in chorea, tuberculous cervical adenitis
Ferrous carbonate mass $FeCO_3$			Med. use: has been used in iron-deficiency anemia. Vet. use: in iron deficiency. Dose: for cattle and horses 6 g; for dogs 200-500 mg
Ferrous chloride $FeCl_2$		Mild irritant	In metallurgy; as reducing agent; in pharmaceutical preparations; as mordant in dyeing
Ferrous hydroxide $Fe(OH)_2$			

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Ferrous iodide FeI_2			As catalyst for organic reactions. Med. use: formerly in chronic tuberculosis. Vet. use: source of iron and iodine
Ferrous oxalate FeC_2O_4	Decomposes at 150-160°C		As photographic developer for silver bromide-gelatin plates; to impart a greenish-brown tint to optical glass (sunglasses, windshields, railroad car windows); for decorative glassware; as pigment for plastics, paints, lacquers
Ferrous oxide FeO	mp 1360°C		In manufacture of green, heat-absorbing glass; in steel manufacture; in enamels; as catalyst
Ferrous phosphate $Fe_3(PO_4)_2$			In ceramics; as catalyst
Ferrous phosphide Fe_2P			
Ferrous sulfide FeS	mp 1194°C		As laboratory source of H_2S; in ceramics industry; as paint pigment; in anodes; in lubricant coatings

(continued)

APPENDIX

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Ferrous sulfate $FeSO_4$		Side effects: G.I. disturbances (e.g. gastric distress, colic, constipation, diarrhea) may occur. In children, ingestion of large quantities may cause vomiting, hematemesis, hepatic damage, tachycardia, peripheral vascular collapse. (Iron medicaments render the feces black or tar-colored and may interfere with tests for occult blood)	In manufacture of Fe, Fe compounds, other sulfates; in Fe electroplating baths; in fertilizer; as food and feed supplement; in radiation dosimeters; as reducing agent in chemical processes; as wood preservative; as weed killers; in prevention of chlorosis in plants; in other pesticides; in writing ink; in process engraving and lithography; as dye for leather; in etching aluminum; in water treatment; in qualitative analysis ("brown ring" test for nitrates); as polymerization catalyst. Med. use: in iron-deficiency anemia, dose 300 mg orally. Vet. use: as source of iron in anemias of livestock. Topically used as astringent
Ferrous thiocyanate $Fe(SCN)_2 \cdot 3H_2O$			As indicator for peroxides in organic solutions
Iron Fe	mp pure 1535°C bp 3000°C		Supplied as ingots, powder, wire, sheets, etc.

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME IRON COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Iron pentacarbonyl $Fe(CO)_5$	bp 103°C Pyrophoric in air; burns to Fe_2O_3	Decomposes readily to produce carbon monoxide. Inhalation may cause headache, nausea, vertigo. Prolonged exposure may cause asphyxia. May be irritating to lungs, but less toxic than nickel carbonyl	To make finely divided iron, so-called carbonyl iron, which is used in manufacture of powdered iron cores for high-frequency coils used in radio and television industry; as antiknock agent in motor fuels; as catalyst in organic reactions